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# Climate Change Impacts on Coastal Land Uses along the Catalan Coast


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TREBALL FINAL DE MÀSTER

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# 1. Introduction

Climate change. It is a word we all have heard of, we all have been said that it is one of the major threats in human history and, however, little is known between the society about its biggest impacts on us. But before we start explaining the true meaning of this phenomenon, we should start by explaining "what is the climate?".

Climate is the average state of the atmosphere, land and water of a particular place on earth, on time scales of seasons and longer. It can be described by a set of atmospheric and surface variables, such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature, and the concentration and thickness of sea ice. To explain the difference between weather and climate, scientists often say, "Climate is what you expect, weather is what you get".[1] In other words, climate is the weather of a particular region, averaged over a long period of time.  It is a fundamental factor in ecosystem health, while most species can survive a sudden change in the weather, such as a heat wave, flood, or cold snap, they often cannot survive a long-term change in climate.

Although climate and climate change are usually presented in global mean terms, there may be large local and regional departures from these global means. These can either mitigate or exaggerate the impact of climate change in different parts of the world. Therefore, global climate is the average of all regional trends, and researchers have concluded that Earth's climate, as a whole, is warming.

The climate in the earth is not static, it's a dynamic system and it's always changing. The problem we have is not the change itself, but the rate of change. While studying past events, we discovered there has always been climate changes in the history of the earth but those changes were produced over long periods of time, giving time to all the species to evolve and adapt. Models predict that Earth will warm between 2 and 6 degrees Celsius in the next century. When global warming has happened at various times in the past two million years, it has taken the planet about 5,000 years to warm or cool 5 degrees. The predicted rate of warming for the next century is at least 20 times faster. This rate of change is extremely unusual and will certainly cause massive extinctions and extreme weather episodes.[2]

Researchers now know that human activities including fossil fuel use, agriculture, and land use have been the dominant causes of the increase in global temperatures, due to everyday-larger concentrations of greenhouse gases in the atmosphere over the past 250 years. In addition, aerosols and land surface changes are also altering Earth's climate, making it extremely likely that human activities have had a big impact and a net warming effect since then.[3]

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[1] (National Science Foundation, et al., 2009)
[2] (NASA, 2017)
[3] (Henson, 2008)

Some of the symptoms that we are experiencing right now are just the beginning of what's on the process of becoming; extreme heat waves (like the one Europe suffered on summer 2003), floods and droughts will be more common than are currently, the ice from the polar regions and glaciers that is melting altogether with the acidification and warming of the oceans is prompting sea level rise, massive record-breaking hurricanes and typhoons like Katrina (2005), Haiyan (2013), Patricia (2015), Harvey (2017) or Irma (2017) and other storm events are becoming more usual and intensifying in strength, bringing with them the feared storm surges and much other symptoms on local and regional scales.

The global-warming problem isn't going to be solved tomorrow, next week, or next year: we're in this one for the long haul. And there clearly isn't one single solution. We need governments to agree and enforce targets; innovators to develop low-carbon energy sources and improve efficiency; and individuals to do their best to reduce their own carbon footprints. Since the process of controlling emissions, concentrations and global temperatures will be really long, scientists and engineers must get ready to prepare the defenses against the threats that humanity is going to be facing sooner or later.

Scientific models are the best tools and a key part of climate change science, in order to help the scientific community to understand these threats and learn how to fight them.

In this particular case study, we are going to focus on the consequences that climate change is going to bring during the following decades, specially sea level rise, to a very specific ecosystem of ours, the coastline of Catalunya, in order to apply wise and efficient measures in the future to protect the most vulnerable spots.

During the past 100 years, an increase in sea levels has been observed at a growing rate. Increasing sea levels have the potential to place important portions of the infrastructure we rely on every day at risk. The transportation infrastructure relies on roads, airports, and seaports to move people, services, and goods around in an ever-connected global economy. Any disturbances of the transportation modes have reverberating effects throughout the entire economic spectrum. The effects include delays, alterations of routes, and possible changes in the origin and destinations of services and goods.[4]

Contributing to the rise in sea level is the rise in global temperature.[5] The increase in temperature has led to quicker melting of ice sheets and glaciers and thermal expansion of the ocean water. The 2007 IPCC report on global scientific consensus regarding climate change already stated that the "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level".[6] Sea level rise (SLR) vulnerability

[4] (Romah, 2012)
[5] (IPCC, et al, 2014)
[6] (IPCC., 2007)

modeling is a specific modeling analysis that tries to predict future risk due to the increase in sea level. Vulnerability in this thesis is defined as areas that are potentially permanently and semi-permanently flooded as a result of sea level rise.[7]

After all this said, the purpose of this project will be to develop a methodology for a sea level rise scenario vulnerability assessment model. With such model we are going to be able to explore the distinct land uses that will be affected by a potential SLR at any given time and any given scenario. With the help of public institutions and universities, we are going to download the necessary data to provide the model of its basic source of material.

Four types of analysis will be made, by coastal cells, municipalities, land uses and vulnerabilities, focusing specifically on the latter.

The final conclusions will try to explain my point of view from 3 basic aspects: The geographic consequences, the model reliability and my personal experience on the matter. With any hope, it will creative a positive impact, that could serve as a foundation not only for me, but for the researching community.

## 1.1 Motivation. Why?

I could say I have two basic personal motivations, if I wanted to simplify things. The first one is related to my origins, the second one to the future of mankind and the challenges that my generation will face the first part of the XXI century.

I was born and raised by the sea, in Lloret de Mar. Some of my very first memories include me learning to ride a bike with my parents along the maritime promenade, or going to the beach to enjoy the waves and the sun with my grandparents. In some way or another, the view, sound and smell of the ocean was always involved in most of my memories. I believe this is a common trait among all of us who have grown up near it.

Lloret has also a very old and deep relation with the ocean. Before tourism, Lloret was a fisherman’s town, depending exclusively on fishing activities and this can be easily observed during Santa Cristina, its traditional festival, that it also involves a boat race along the coast. My hometown is nowadays one of the most touristic places in Catalonia after Barcelona, known by its nightlife and also because of his spectacular coast, La Costa Brava. As a Mediterranean touristic town, Lloret depends on the summer season in order to develop his economic activities and business, and the center of this activities and the most iconic place in the town, it’s his main beach.

Along the passing of the years, I’ve seen how every winter, huge portions of sand beach disappear with every storm, the lower area of the town gets flooded and

[7] (Romah, 2012)

parts of its promenade are destroyed. With climate change, and SLR, this phenomenon will most likely get worse.

What I mean by all this, is that the sea is the basic source of resources, work and leisure for the majority of the coastal towns, all of them depending on its mood, the ocean is untamable. It exerts a great influence to them and to its inhabitants. I now believe that is because of this influence that I always felt a great attraction to it; the feeling of smallness, his rage as source of storms and hurricanes, the stories of great journeys, the mysteries of its depths… the ocean has always been there and I always wanted to know more about it. In the case of this study, I wanted to understand better the relation between land and sea, how the coast is affected by the ocean and how the climate change and the SLR will affect the places that live on my memories.
The second reason has more to do with my sense of involvement in global problems. This century, the world will face many threats, including climate change, social inequality, overpopulation, pollution, climate and war refugees, political conflicts, terrorism, pandemic events… although this may sound apocalyptic, we also have reasons to be optimistic. In this century, we may be sending people to Mars, the technological innovation is pushing hard to reach new limits every day, green energy production is going to overcome fossil fuels soon, our generation is the best educated and prepared in the history of mankind… even though, no one, not even the most prepared, can face all these threats alone and win, as a multidisciplinary block, collaborating between us, we can prove that the potential of human race is all but weak. I may be just an average student but if I can just put my grain of sand in trying to solve at least one of these major problems, I will be more than satisfied with myself. We owe it to our little pale blue dot, our planet.

## 1.2 Objective

Climate change is expected to increase the mean water level (MWL) and consequently have an impact on present coastal land uses and activities. The main objective is to assess the impacts of the sea level rise on coastal land uses along the Catalan Coast. The study will consider the scenarios defined recently by the IPCC 2014.

## 1.3 Contents

This thesis is structured as follows

### Chapter 1. Introduction

It presents the introduction, the personal motivation and the main objective of the thesis.

### Chapter 2. Methodology

On this chapter, we got to meet the basic characteristics of the geography of the Catalan Coast, the land uses and the various economic activities that take place in it. We will take a look on how SLR predictions are calculated and which prediction are we going to use for our model. We will also describe the state of the art of the bathtub methodology as well as enumerate the sources of the different GiS layers that we are going to use. And finally, we are going to analyze the loss of surface with bathtub method in order to find vulnerabilities.

### Chapter 3. Results

In this chapter, we will present the results obtained from chapter 2.

### Chapter 4. Conclusions

This last chapter we will enunciate our final conclusions on this case study.

# 2. Methodology

## 2.1 The Catalan Coast

Catalonia is a region situated in northeast Spain, of which Barcelona is its capital. It has a very marked geographic diversity, taking into account the relatively small size of its territory (about 32.000 km). The geography is conditioned by the Mediterranean coast to the east, with 580 kilometers of coastline.[8]

*Illustration 1. Location of Catalonia*

The Catalan coast presents almost all type of littoral environments. The northern sector is composed by the presence of cliffs (about 280 km of the total length) and prominent headlands delimiting pocket beaches that span a vast range of dimensions and are typically of coarse sediment. The southern part is typically represented by low lying beaches of fine sediments. The central part is under the influence of the metropolitan area of Barcelona and concentrates most of the marinas and urban settlements which have created a segmented coastal landscape due to an important coastal protection activity. The main morphological features are the Ebre delta unit at the south (a 50km sandy fringe), the straight segmented and relatively coarse sand beaches at the center (represented by the Barcelona–Maresme system) and the Tordera delta and Costa Brava pocket beaches and cliffs at the North tract.[9]

### 2.1.1 Main Features

Catalonia coast stretches from Cape de Creus in the north up to river Senia in the south.

The proportion of square kilometers of surface per kilometer of coast in Catalonia is 55 $km^2/km$, which means it has a very large maritime exposure. It also has a very high population density, with over 10.000 inhabitants per kilometer of Coastline, much higher than the Spanish trend, which is about 5.000 inhabitants per km of coast. In that sense, Catalonia critically needs to try to understand which are the threats that the Sea Level Rise is going to bring, because more people will be affected by it than in any other regions.

The main features of the Catalan coast are:

• Total length of coastline: 580 km

• Length of Beaches (urbanized and non-urbanized): 280 km

[8] (Generalitat de Catalunya, 2016 )
[9] (Sánchez-Arcilla, 2016)

• Length of urbanized coast up to 100 meters deep (compact urbanization from towns and cities plus diffuse urbanization from hotels, campings and familiar houses): 340 km, which translates into 59% of the entire Catalan coast.

• Length of ports and maritime works: 40 km

• Length of coastline that includes river deltas: 1.2 km

• Administrative boundaries:
- Number of districts ................................. 12

Including: Alt Empordà, Baix Empordà, La Selva, Maresme, Barcelonés, Baix Llobregat, Garraf, Baix Penedés, Tarragonés, Baix Camp, Baix Ebre and Montsià.

- Number of municipalities ........................ 70

Which include the following (North to South):

**L'Alt Empordà**
- Portbou
- Colera
- Llançà
- El Port de la Selva
- Cadaqués
- Roses
- Castelló d'Empúries
- Torroella de Fluvià
- Sant Pere Pescador
- Vilamacolum
- Riumors
- L'Armentera
- L'Escala

**El Baix Empordà**
- Torroella de Montgrí
- Pals
- Begur
- Palafrugell
- Mont-ras
- Palamós
- Calonge
- Castell-Platja d'Aro
- Sant Feliu de Guíxols
- Santa Cristina d'Aro

**La Selva**
- Tossa de Mar
- Lloret de Mar
- Blanes

**El Maresme**
- Malgrat de Mar
- Santa Susanna
- Pineda de Mar
- Calella
- Sant Pol de Mar
- Canet de Mar
- Arenys de Mar
- Caldes d'Estrac
- Sant Vicenç de Montalt
- Sant Andreu de Llavaneres
- Mataró
- Cabrera de Mar
- Vilassar de Mar
- Premià de Mar
- El Masnou
- Montgat

**El Barcelonès**
- Badalona
- Sant Adrià de Besòs
- Barcelona
- L'Hospitalet de Llobregat

**El Baix Llobregat**
- El Prat de Llobregat
- Viladecans
- Gavà
- Castelldefels

**El Garraf**
- Sitges
- Sant Pere de Ribes
- Vilanova i la Geltrú
- Cubelles

**El Baix Penedès**

- Cunit
- Calafell
- El Vendrell

**El Tarragonès**
- Roda de Barà
- Creixell
-Torredembarra
- Altafulla
- Tarragona
- Vila-seca
- Salou

**El Baix Camp**
- Cambrils
- Mont-roig del Camp
- Vandellòs i l'Hospitalet de l'Infant

**El Baix Ebre**
- L'Ametlla de Mar
- El Perelló
- L'Ampolla
- Camarles
- Deltebre
- L'Aldea
- Tortosa

**El Montsià**
- Sant Jaume d'Enveja
- Amposta
- Sant Carles de la Ràpita
- Alcanar

• Watersheds involved: Muga, Fluvià, Ter streams of the Costa Brava, Tordera, Maresme streams, Besòs, Llobregat, Garraf streams, Foix, La Bisbal stream, Gaià, Francolí, Southern streams, the Ebre and Senia.

• Land occupation: The human presence had in 2002 an area of 1,520 square kilometers (4.7% of Catalonia territory) and concentrated, in general, on the coast, especially in the metropolitan area of Barcelona.[10]

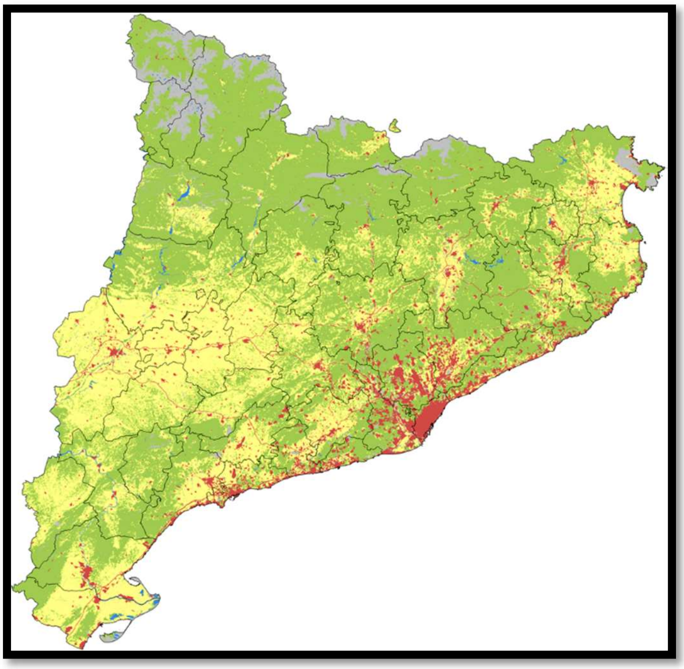


*Illustration 2. Human Settlements Concentration*

[10] (Agencia Catalana de l'Aigua, 2012)

### 2.1.2 Geography

The Catalan coast has few geographic accidents, the most noteworthy of them are Cape Creus and Gulf of Roses in the north and Ebre delta in the south.

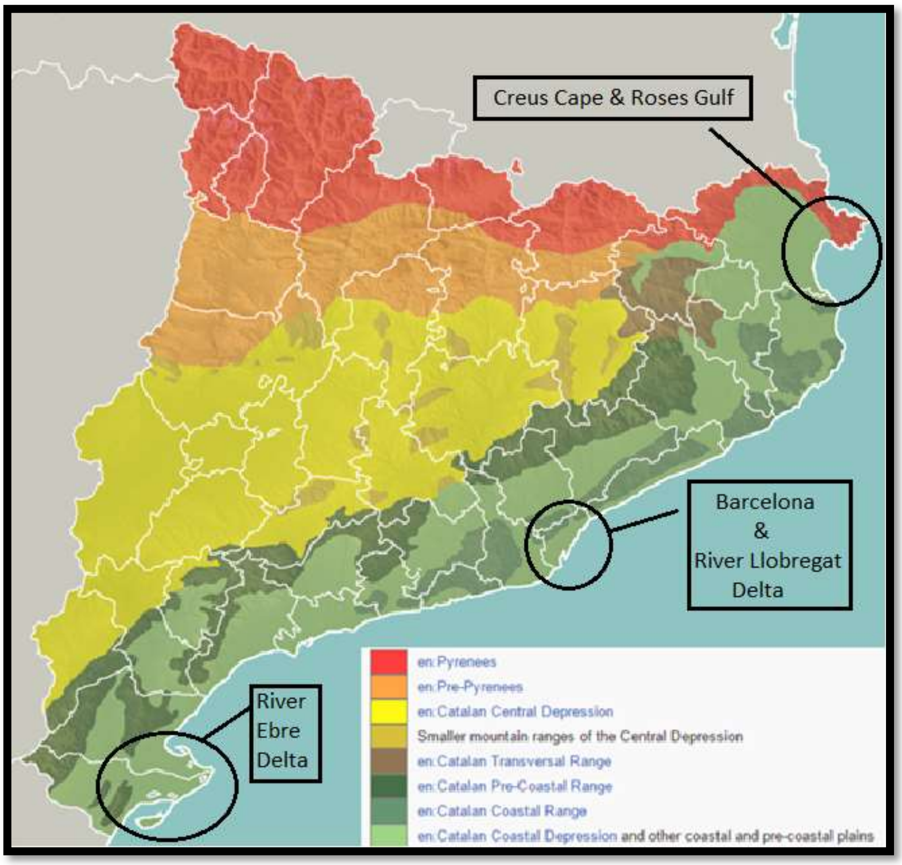



*Illustration 3. Catalan Geography*

Starting in the north, the Costa Brava, from the Pyrenees until the coastal town of Blanes, characterized by tall cliffs and small hidden coves. Then follows a long line of beaches parallel to the coastal mountain range in the Maresme area.

*Illustration 5. Costa Brava*

*Illustration 4. Maresme Beaches*

Barcelona coast is characterized by artificial beaches and a large commercial port extending over more than nine kilometers. The southern part of the port was developed on the plain of the Llobregat delta, which after the port, draws a smooth coastline of more than 18 km. Then, the Garraf Massif articulates the remarkable cliffs and shores of the coast and, until after Sitges, not to be straight again.

*Illustration 6. Barcelona Coastline and Port*

*Illustration 7. Garraf Massif*

Continuing along the south, we find the port of Tarragona. This is the second port of Catalonia and extends over five kilometers before entering the Cape of Salou.

*Illustration 8. Costa Daurada*

*Illustration 9. River Ebre Delta*

The beaches in this area are named Costa Daurada. To the south, the coast is again characterized by soft and less human occupation. The last major landform is the Gulf of Sant Jordi and the lowlands of the Ebre delta, where there are islands and peninsulas, such as Punta del Falgar north and La Banya in the south. After river Ebre delta there's a small strand of beaches before reaching Valencia. Catalan sand beaches are usually gold, and with a tendency to be granular in the north and thinner in the south.[11]

[11] (Wikipedia Cooperators, et al, 2016)

### 2.1.3 Climate

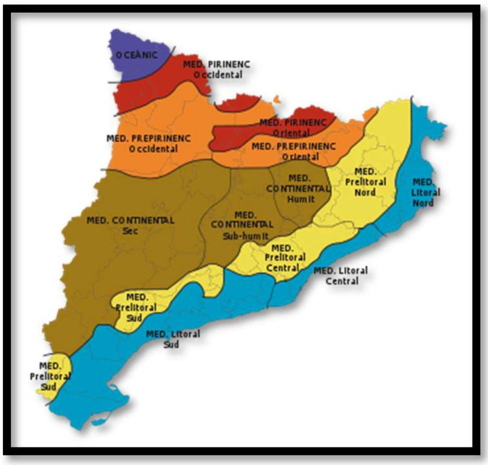



*Illustration 10. Climate map*

The main characteristic of the Mediterranean coast climate is the mild winter (sometimes it takes several years for the thermometer to drop below zero degrees) which is not normal given the Latitude of Catalonia and, in summer, the average temperatures are between 24°C and 25°C with strong humidity, creating sultriness, but with marinade that makes the average maximum temperature not reach 30°C. Average annual rainfall in the coastal area are between 700mm (Baix Empordà) and 480mm (Tarragona). The maximum rainfall is in autumn, with potentially strong heavy showers. The irregularity of rainfall is typical of the Mediterranean climate.[12]

### 2.1.4 Tides and Sea Behavior

This coast is located in a micro-tidal environment. The astronomical tidal range is less than 0.4 m although during storms the associated surge can reach values up to 1 m. The mean offshore significant wave height for the area is 0.7m with an associated wave period of 7 s. The directional distribution of waves at the Northern and Southern parts of the coast show a predominance of NW and N components whereas at the central part the East and South directions are dominant.[13]

The maximum recorded Hs is about 6 m (with Hmax up to 10 m) and peak periods of about 14 s.

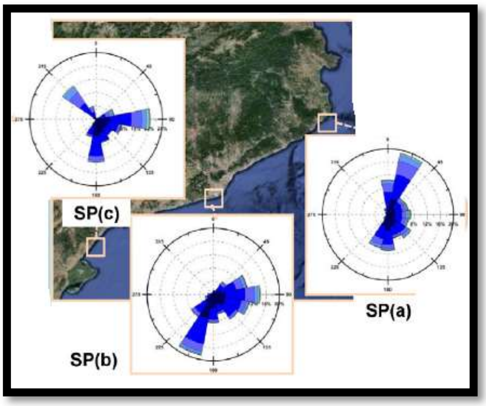



*Illustration 11. This picture shows the wave directional diagrams at different locations along the coast obtained from the existing wave buoys for the period 1984 to 2007 along the Catalan coast.*

[12] (Wikipedia Cooperators, et al, 2016)
[13] (Sánchez-Arcilla, 2016)

As it can be seen, North-Eastern and Eastern components feature the highest waves whereas the southern component, although present, has typically lower values.

Natural and artificial barriers modulate sediment dynamics and divide the coast into littoral cells. The average beach has a width of about 37 m, with a mean sand size from 0.2 to 1.8 mm (median value of about 0.7 mm) and a foreshore slope steeper than 1/10. The spatial distribution of sediment along the coast reflects the differences in river basins, which have historically provided solid discharges to the coast, later reworked by wave action. Beaches located close to the mouth of the main rivers present sediment finer than for beaches fed by ephemeral streamflows (usually very short). This general pattern has been modified in the last decades by the supply of allochthones sediments (of marine and terrestrial origin) in a considerable number of beach nourishment operations that have created an artificial morphodynamical signature in most of the beaches. As an example of this alteration, only in the central part of the Catalan coast more than 10 million cubic meters of sand have been supplied in different beach nourishment operations.[14]

### 2.1.5 Soils, Activities and Land Uses

Urban sandy beaches are typically bounded in their backside by a seafront promenade and infrastructures like streets, roads, railways and houses. In the last years, the maintenance and development of promenades has been one of the major investments undertaken by the Spanish government, with more than 50 M€ only in Catalonia during the last two decades.[15]

The shoreline changes for the period 1995–2004 show a general retreat, with more than 70% of Catalan beaches eroding[16], with average rates of about −2.1 m/year and of about −3.3 m/year when the Ebre delta is considered. Only 24% of the beaches have experienced accretion with an average rate of about +1.5 m/yr. and mainly correspond to areas located at the end of coastal cells which bank up the sediment from the upstream part of the cell or, in the particular case of the Ebre delta, from its ending spits.

It is accepted that the urban development at the Catalan coastal started in the 70s under low regulatory conditions. The lack of a general management strategy followed by the construction of coastal promenades, second houses (fed by tourism needs) and existing urban growth pressure jointly with the regulation of river basins have led to the present sediment starvation needing coastal protection.[17]

This resulted in nowadays high population density along the coast, that contributes to raise the vulnerability in these areas. This squeezing requires a

[14] (Gracia et al., 2013b)
[15] (CEDEX, 2013)
[16] (CIIRC, Departament de Política Territorial i Obres Públiques., 2010)
[17] (Sánchez-Arcilla, 2016)

minimum beach width to support coastal functions and to defend the hinterland (infrastructures and territory). During the second half of the 1980s and early 1990s, beach nourishment was the common solution to fight against erosion, with more than 10M m3 of sand in about 10 years of which only a small fraction is still remaining in place.[18]

The lack of management and planning to fight against erosion, the scarcity of adequate quality of sediment plus the fragile economic situation has led to a reactive policy on this matter, where actions are taken only after impact, thus leading us to the actual degenerative state of the coast.

A perfect example of this situation is the central Catalan coast (Barcelona - Maresme). The area is the longer tract with eroding beaches and also where most of the growing beaches are found. This behavior is basically due to the net littoral drift, from north to south, and the existence of numerous marinas interrupting the alongshore dynamics. This restriction creates a local shoreline retreat in the north and a lower accretion at the southern part of the beaches, linked to the downstream barrier.

This area receives the Eastern-component waves which are the most energetic and it also has the narrowest retreat zone due to high urbanization (settlements and infrastructure), so during high energy episodes, its natural onshore dynamics get blocked.

*Illustration 12. Example of high urbanized area few meters away from the shoreline (Sant Pol de Mar, Maresme).*

This situation has led to a sediment redistribution pattern which is incompatible with the socio-economic demand of the area. The alongshore sediment blockage generated by the construction of structures and the near total decrease of river

[18] (Gracia et al., 2013b)

sediment supply (large enough in size to be stable for the emerged beach) has resulted in a sediment budget imbalance in most littoral cells.[19]

Due to the scarcity of sediment for many sectors in the Catalan coast the actions undertaken in the last 20 years (also extensive for the rest of the Spanish territory) have been unsuccessful to maintain a sandy belt as required by tourism and hinterland protection.

The land uses along the coast can vary from agricultural use, to tourism based business and sport centers. For deeper understanding and accuracy on the land uses, Annex 5.1.3 shows maps and related data.

## 2.2 Flooding Mechanisms

### 2.2.1 Sea Level Rise Projections and Vulnerability

In order to create a SLR vulnerability model, an understanding of the different SLR projections is required. The projections are important in the model creation process for determining the amount of SLR to model for. The intent of this project is not to project the rate and time of SLR events, but to rely on work done by other researchers as an input into the SLR vulnerability model.

Part of the methodology for determining SLR has been through the use of historical tide gauge stations located throughout the world and lately as well as satellite data.

Recent past observations show global mean sea-level changes (GMSL) since the 1880s of around 0,2m (0,19m, 1901–2013) at averaged rates of 1,7–1,8 mm/year, though with strong temporal (decadal scale) and regional variations. During this interval mean global sea-surface temperatures (SST) have also risen by 0.8 °C, altering storminess in many ocean regions.[20]

This research thesis will use *Sánchez-Arcilla, A., et al., Managing coastal environments under climate change: Pathways to adaptation, Sci Total Environ* (2016), scientific article (with authors from my same university department), as a source for the SLR predictions along this century for the NW Mediterranean coast.

In considering SLR, we must consider the different RCP scenarios (*Representative Concentration Pathways*) of emissions by 2100. Explained easy; SLR rates depends on RCP (emissions). Different RCP scenarios lead to different SLR projections, on a scale of biggest emissions to lower emissions, SLR is also big to low.

RCP scenarios are emission scenarios on the evolution of estimated concentration of greenhouse gases in the atmosphere during the XXI century, established by the Intergovernmental Panel on Climate Change (IPCC) for the

[19] (Sánchez-Arcilla, 2016)
[20] (IPCC, et al, 2014)

preparation of its fifth assessment report. There are basically 3 different RCP possibilities; the first one and more dangerous is RCP 8,5, where the worst-case scenario is considered and emissions get higher and higher during this century, which leads to a higher SLR. RCP 4,5 and 2,6 are more conservative predictions that will also be considered in this study.

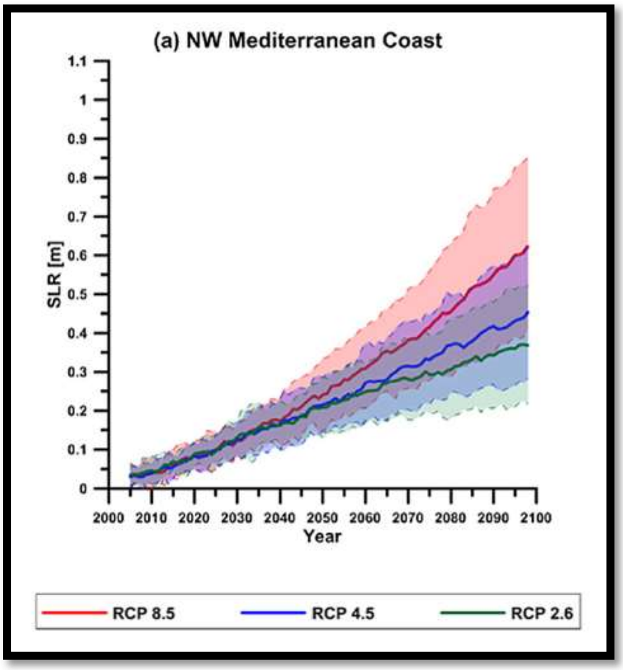



*Illustration 13. Projected regional rise in sea level up to 2100.*[21]

Future climate projections for European coasts, based on model ensembles, show SLR rates similar to global values[22]. For low greenhouse gas (GHG) emission scenarios (RCP 2.6) mean SLR is likely to be in the range of 0,26– 0,54 m above 1990 levels by 2080–2100. For higher emissions (RCP 8.5) mean SLR will be in the range 0,45–0,81m and continuing to rise between 1–3m by 2300, depending on levels of continued GHG emissions.

Current satellite altimetric observations of SLR rates for European waters, also supported by tide gauge data, commonly show values above 3.2–3.4mm/year[23], except for regions of significant geotectonic/subsidence (e.g., deltas). These rates are likely to accelerate beyond 4–5 mm/year by the mid-21st century.

There are many different trends of RCP, and they tend to diverge in the second part of the century, which would mislead the governments and stakeholders to justify postponing response decisions since the larger part of uncertainty and impacts will start to happen by 2040-2050. This would be a catastrophic mistake since most of the responsive actions take years (if not decades!) to be applied and we need to anticipate those of most critical effects.

[21] (Sánchez-Arcilla, 2016)
[22] (Lowe, 2010)
[23] (EEA, 2014)

Apart from these different SLR scenarios, we also must consider the wide range of different types of coasts present in the Catalan littoral that lead to different vulnerability levels; where coasts with enough space to evolve and adapt will represent areas with lower vulnerability, coasts within the urban areas with less space will feature higher risks and vulnerabilities.

The likely future increase in population for our studied coasts[24], associated to industrialization, urban growth and expanding tourism, will bring the numbers of people living in the littoral closer to the levels elsewhere in Europe. This means more than 25% of Europe's current population living at the coast[25]. Continuation of the established upward trend in this population growth will increase the vulnerability of coasts to the impacts of future SLR and storminess under climate warming. The Catalan Coast is no exception to this trend.

### 2.2.2 Bathtub Method

Bathtub models have been used to identify areas that may be subject to sea level rise. It gives a simplified yet very powerful visualization of the problem with a relative small amount of inversion of calculus and time. However, a bathtub model only considers the elevation of the ground above a reference elevation for determining SLR vulnerability. In a bathtub model the terrain is considered to remain constant. As the sea level rises, inundation occurs at locations between above the zero datum and below the new sea level.

The main disadvantages of this type of model is that is does not consider urban water control infrastructures such as dikes and canals that lead to overestimation of flooding, or groundwater levels and storm surges that can lead to underestimation of it. Anyhow, it’s a simplified method to calculate SLR that can prove to be useful and its currently used by many governmental organizations such as counties and municipalities due to the ease of data acquisition and model creation. Regional studies using the bathtub approach have been implemented as well. For example, in United States, a collaboration between the U.S. Geological Survey (USGS)[26] and National Oceanic and Atmospheric Administration (NOAA)[27], in *Visualization of Sea-Level Rise for Alabama, Mississippi, and Florida,* a bathtub model analysis was applied to determine sea level vulnerability in the noted states (USGS 2011). The results of the study indicated the locations of potential SLR vulnerability in the three-state region.[28]

#### *2.2.2.1 Tidal Surface adjusted bathtub model*

Currently, multiple organizations have implemented a methodology that uses the influence of a tidal surface elevation in modeling the vulnerability to sea level rise.

[24] (Neumann, 2015)
[25] (IPCC, et al, 2014)
[26] (USGS, 2016)
[27] (NOAA, 2016)
[28] (Romah, 2012)

The methodology as described by NOAA is an adjusted bathtub model that takes into account local and regional tidal variability and hydrological connectivity. In this model type, a water datum such as the mean higher high water (MHHW) datum is considered as the base datum elevation, instead of a constant zero mete value to represent the current sea level.

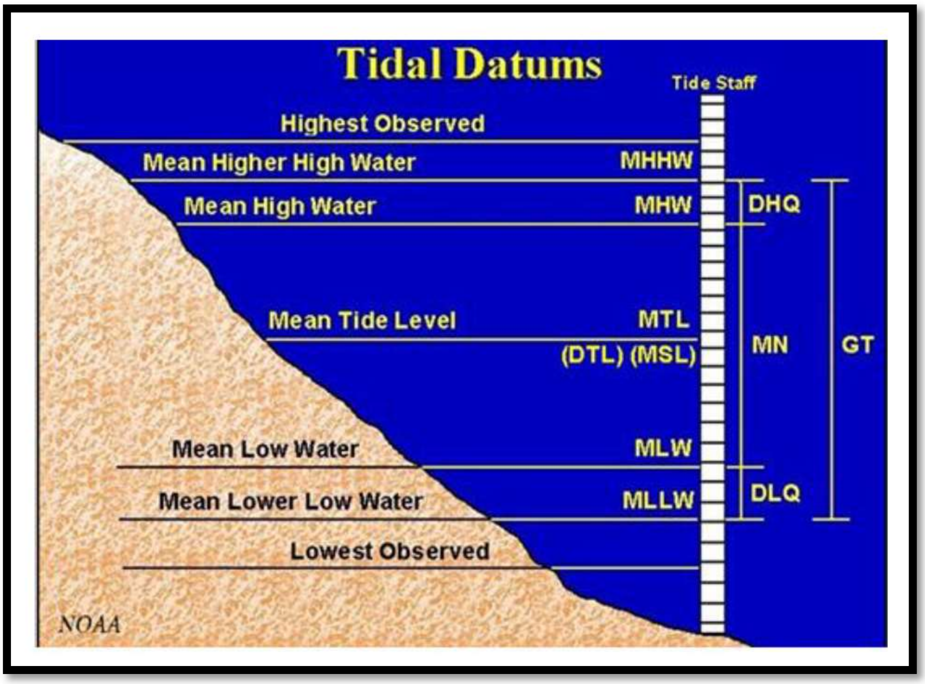



*Illustration 14. Tidal Datum from NOAA 2011*

The tidal datum elevation is used to represent land areas that are currently inundated daily, which form the delineation of land inundated due to abnormal events such as sea-level rise. The importance of the tidal datum surface is that it accounts for underestimation of SLR that a standard bathtub model would not identify in locations where the mean high tide level exceeds the zero-foot elevation datum.[29]

If the place that is going to be projected has very important tides, it can strongly influence the results from an SLR study, so this method would be the default choice. Given that the case study of our interest is situated in the Mediterranean, where the tides have little influence on the results, we will leave the use of tidal surfaces as an optional output. Nevertheless, is interesting to mention that this method exists and its importance on geographical areas subject to high tides makes its use totally compulsory.

### 2.3 Sources of Data and GIS layers.

There are many institutions and web services that altruistically provide and share data from all around the world about the sea levels, the land use and digital elevation models that are a basic tool for the development of geographical

[29] (Romah, 2012)

studies. The following sites and institutions are fundamental for the development of this particular case study.

- "Institut Cartogràfic i Geològic de Catalunya. Generalitat de Catalunya".

**The 2x2 digital elevation models and orthophoto's grid** will be downloaded from their web service. The data was collected between 2008 and 2011. Their basic characteristics will be explained in part 2.4.1.1. from this study.

- "Ministerio de Agricultura i Pesca, Alimentación y Medioambiente. Gobierno de España".

The **Land Maritime Public Domain** line will be downloaded from their web page. Their data was last updated in March 2017.

- "Centre de Recerca Ecològica i Aplicacions Forestals. Universitat Autònoma de Barcelona".

**The land uses** will be downloaded from their webpage. The data that will be used was created in 2009. Their basic characteristics are:

Orthophoto Scale: 1:2.500
Resolution: 0,25 m
Work Scale 1:1.000
Infrared Technique: Yes
Minimum catch surface: 500 m²
Minimum width: 10 m
Categories: 241

**The Sea Level Rise Scenarios** considered, will be taken from the latest IPCC report from 2014.

Apart from this web sites, where we will download the data to be used in ArcGis, many other web pages, articles and even books will be used for gathering information that will help us to redact this thesis and put things in order. All of the sources will be pertinently referenced and added to the bibliographic section of this study.

## 2.4 Methodology for Bathtub Method

The steps contained below are the steps that will be followed to create the bathtub model. In the section 2.2.2 Bathtub Model of this case study, the definition of the model can be found to get a better approach.

### 2.4.1 Base Layer DEM

#### *2.4.1.1 DEM Data Acquisition*

The most important factor in determining SLR vulnerability is the initial land surface elevation. As the elevation increases, the effects of SLR induced problems are reduced, especially in regions that have high coastal ridges that continue to increase in elevation as you travel inland. The first step in this analysis was locating and obtaining the best vertical resolution Digital Elevation Model (DEM) available. The current state of the art of technology for DEM gathering uses planes equipped with LiDAR equipment (Light Detection and Ranging). LiDAR uses the amount of time required for a radar signal to return to the aircraft detector to determine the elevation. All our DEM data was obtained from Institut Cartogràfic i Geològic de Catalunya.[30]

##### 2.4.1.1.1 Recruitment

The data used from ICC, Terrain Elevation Model 2 x2 meters of Catalonia (TEM-2) v1.0, is updated data from the project LiDARCAT.

The project LiDARCAT covers with LiDAR data the entire surface of Catalonia with a minimum density of 0,5 points/m$^2$ (See illustration number 15). The cloud of points is divided into blocks of 2x2 km and then calibrated and adjusted using control areas. Afterwards, an initial automatic classification is made from the adjusted points, in order to assign every point to the type of element that it represents. Later on, a quality control process is made, that evaluates the initial automatic classification of points of the terrain and the bugs that are found are corrected manually. Once all refined points of land are depurated, a new automatic classification of the points that are not ground is made, to classify the buildings, vegetation, towers and power lines.

To obtain the TEM (Terrain Elevation Model), the 2x2 km blocks are merged together and the cartographic cutting is made, matching the sheets of the Topographic database of Catalonia 1:5000 (BT-5M) v2.0 with overlap, where only ground points are considered from all the classes of LiDARCAT points.

Occasionally, breaklines are added to make the cloud points more compact, in order to avoid sudden changes in slopes that have not been sufficiently defined. Finally, with the points of class "ground" and the breaklines of the slope, by triangulation, the model of regular grid is generated.

[30] (Generalitat de Catalunya, et al, 2016)

Quality checks are carried out of each process.

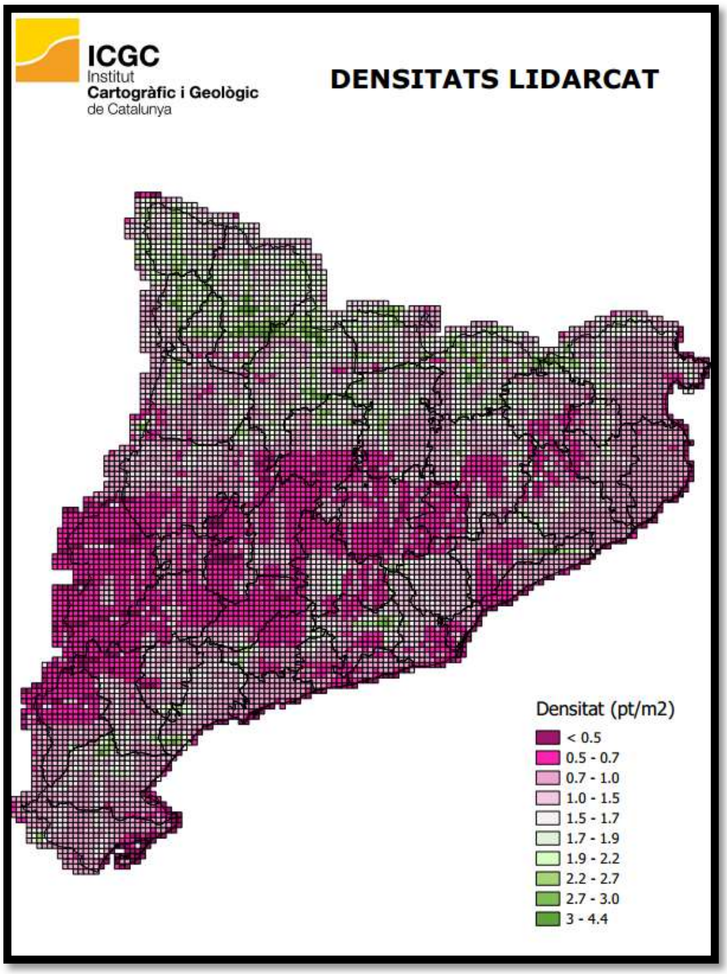
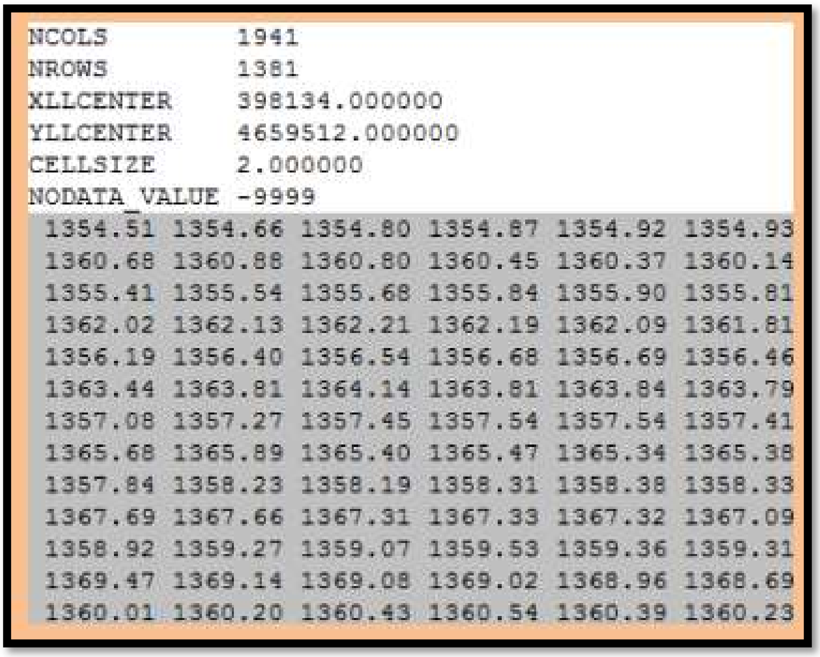



*Illustration 15. Density of points from LiDARCAT.*

#### 2.4.1.1.2 Distribution Format

The files are distributed in ASCII format ESRI GRID, compatible with most programs that can read regular grid patterns in ASCII format.

The header indicates the number of columns (NCOLS), the number of rows (NROWS), south west pixel coordinates (XLLCENTRE YLLCENTRE), the size of the mesh step in meters (CELLSIZE), and the value assigned to the pixels that had nonexistent value of altitude (NODATA_VALUE). Below are elevations arranged by rows from north to south, and from west to east each row. The levels are given in meters and separated by a space. Depending on how they are generated, there can be line breaks.



```
NCOLS         1941
NROWS         1381
XLLCENTER     398134.000000
YLLCENTER     4659512.000000
CELLSIZE      2.000000
NODATA_VALUE  -9999
 1354.51 1354.66 1354.80 1354.87 1354.92 1354.93
 1360.68 1360.88 1360.80 1360.45 1360.37 1360.14
 1355.41 1355.54 1355.68 1355.84 1355.90 1355.81
 1362.02 1362.13 1362.21 1362.19 1362.09 1361.81
 1356.19 1356.40 1356.54 1356.68 1356.69 1356.46
 1363.44 1363.81 1364.14 1363.81 1363.84 1363.79
 1357.08 1357.27 1357.45 1357.54 1357.54 1357.41
 1365.68 1365.89 1365.40 1365.47 1365.34 1365.38
 1357.84 1358.23 1358.19 1358.31 1358.38 1358.33
 1367.69 1367.66 1367.31 1367.33 1367.32 1367.09
 1358.92 1359.27 1359.07 1359.53 1359.36 1359.31
 1369.47 1369.14 1369.08 1369.02 1368.96 1368.69
 1360.01 1360.20 1360.43 1360.54 1360.39 1360.23
```

*Illustration 16. File header data.*

##### 2.4.1.1.3 Metadata

A level distribution unit can check the dates of the flights LiDAR, from which the TEM was generated, by the file "MET2-Tall5m_LiDARCAT-DataVol" which can be downloaded from the website of the ICGC in shapefile format.

In our case, the obtained data belong to different periods in time, expressed in the following map.

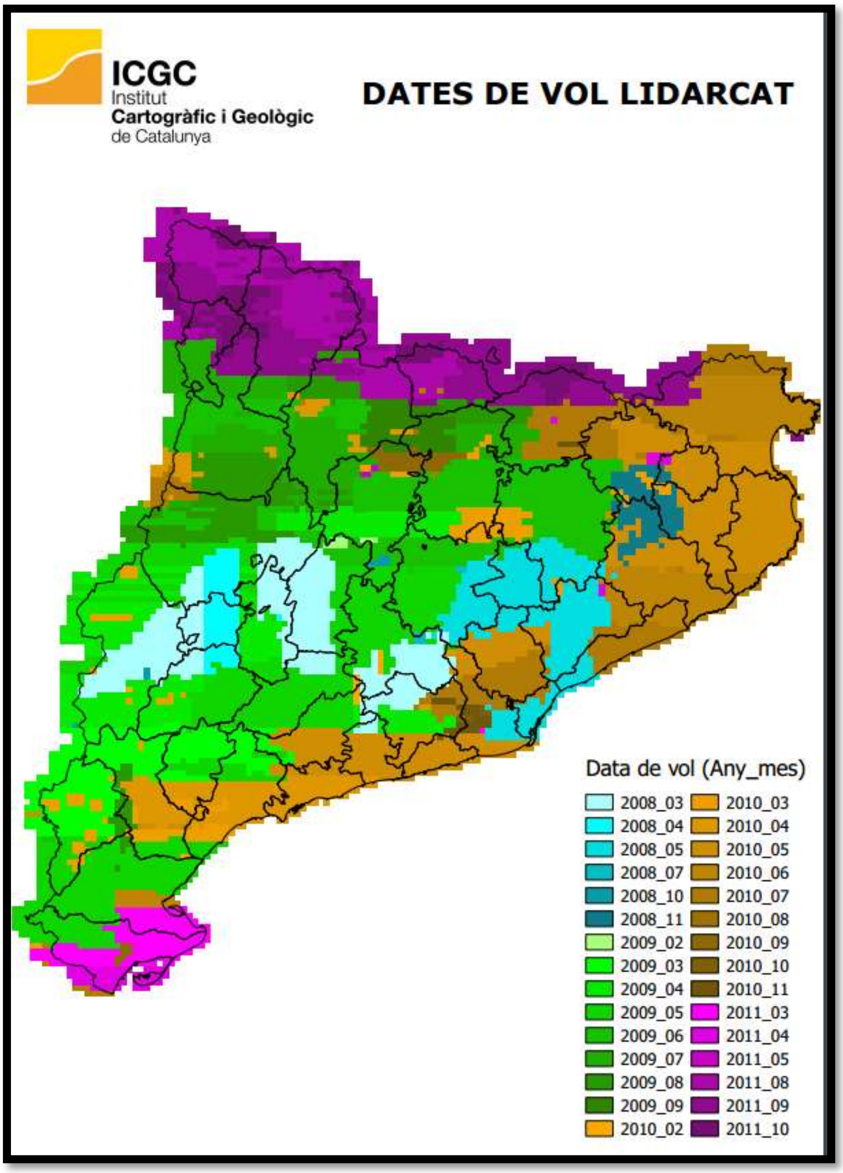



*Illustration 17. Dates from the different LiDAR flights.*

#### 2.4.1.1.4 Quality

It is estimated that the absolute vertical accuracy in flat areas and few vegetation, corresponds to an average error of 0.15 square meters.

Regarding the consistency of the format, the data is stored correctly according to the requirements of ESRI GRID format ASCII.

#### 2.4.1.1.5 Structure and content

Terrain Elevation Model 2x2 meters of Catalonia (TEM-2) is a v1.0 digital terrain model of regular grid that contains orthometric altitudes, expressed in meters with two decimals, distributed according to a grid with mesh size of 2 meters.

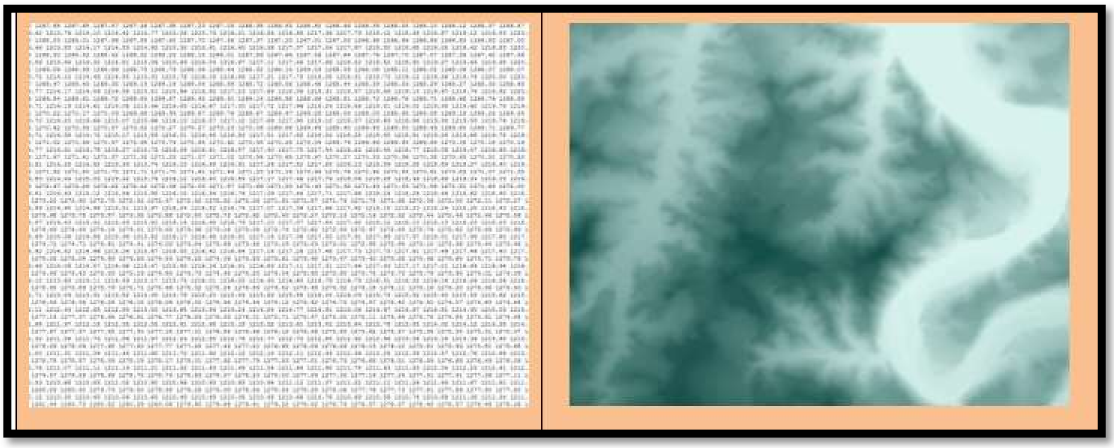


*Illustration 18. Structure and Contents vs. Actual Visualization of Data*

##### 2.4.1.1.6 Reference Systems

**Geodetic reference system**

The geodetic reference system is called ETRS89, established as the official one by the Royal Decree 1071/2007, consisting of the ellipsoid GRS80 fixed in the stable Eurasian continental plate and coincident with ITRS at the epoch 1989.0 and consistent with the current satellite positioning systems (GPS).

The reference system is materialized on the territory with the Geodetic Network Utility of Catalonia, belonging to the Integrated Geodetic Positioning System of Catalonia, being the Cartographic and Geologic Institute of Catalonia responsible for its construction and maintenance and to determine and distribute this official coordinate of its vertices, which are the result of Geodesic compensation.

The geodetic coordinates are positive in northern Ecuador for the latitude and East of Greenwich for length.

**Coordinate System**

The planimetric system of representation is the Universal Transverse Mercator (UTM). This projection is set to coincide with the regulatory Royal Decree 1071/2007, which is the projection for Catalonia according to ETRS-TM31A.

The order of the coordinates is (Est (X), North (Y)).

**Vertical Reference System**

The altitudes are referred to the surface defined by the average level of the sea. In Catalonia, the origin of altitude is the mean sea level in Alicante. The geoid that is used is the EGM08D595.[31]

[31] (Institut Cartogràfic i Geològic de Catalunya, 2016)

### 2.4.2 DEM Model Creation

A major issue when recompiling the data was that it was impossible to discharge one big grid representing all the coastline of Catalonia, so individual downloads from different sectors had to be mosaicked back into larger pieces that could then be modified to create a complete DEM model of the coastline. We selected the 2x2 DEM models from the ICC. We had to download more than 100 different squares that all together compose the totality of the coast.

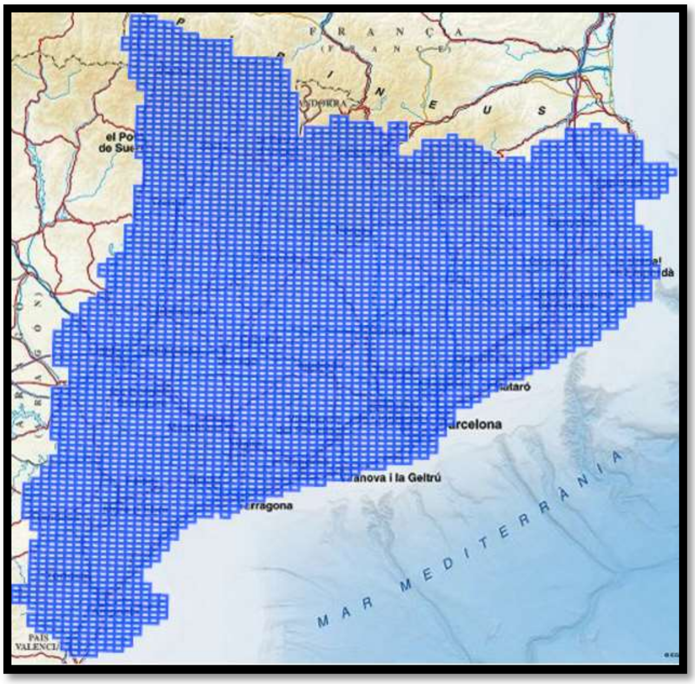



*Illustration 19. ICC url for DEM data downloads.*

#### *2.4.2.1 Coast Rasters Preparation (Mosaics)*

Using ArcGis v10.3, we transformed the various DEM's into rasters with the following command line ArcToolbox > Conversion Tools > To Raster > ASCII to Raster.

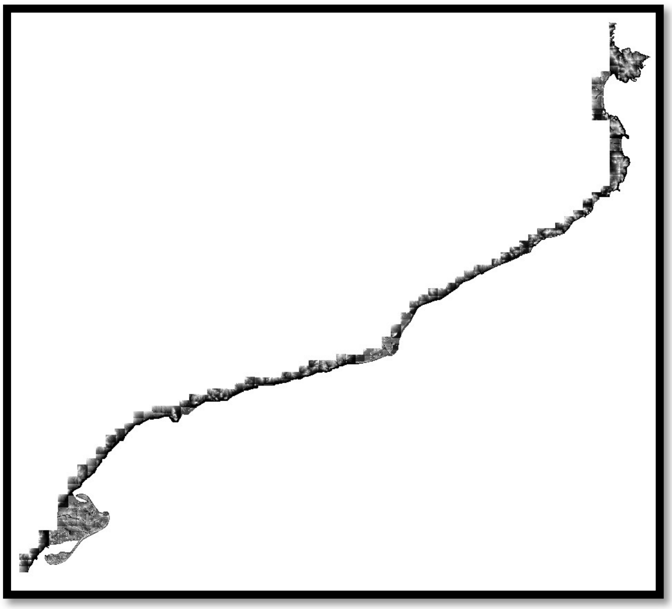


*Illustration 20. Grid of Rasters Created in ArcGis.*

As it easily observable, the Catalan Coast silhouette stars to appear in the screen, though the different rasters have different chromatic schemes because of the different altitude values. Now we need to unify them in one single or multiple bigger rasters with one single chromatic scheme to help us easily manage the data.

Once the raster conversion was made, we had to mosaic together the different pieces. To do so, we must apply ArcToolbox > Data Management Tools > Raster > Mosaic Dataset > Create Mosaic Dataset. Then, the following window will appear.

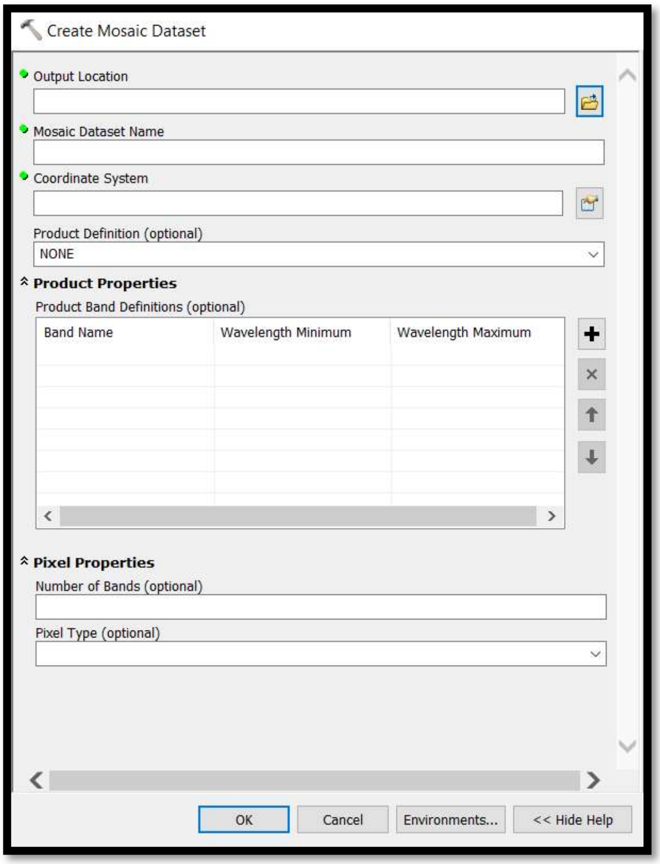



*Illustration 21. Create Mosaic Command Window.*

Here we will create a new geodatabase that will be used as our blank file where to apply the mosaic, and then give it a name.

The Coordinate system of the output raster, will be the same from ICC reference system, Universal Transverse Mercator (UTM), ETRS-TM31A.

Finally, we should specify the pixel type, according to ArcGis description, is the bit-depth (radiometric resolution) of the output raster dataset. If this is not specified, the raster dataset will be created with a default pixel type of 8-bit unsigned integer. We selected the 32-Bit Float for better quality, which can accept 32-bit data type and most importantly, supporting decimals, key for the development of this study..

Once this is done we press “Ok” and move on to ArcToolbox > Data Management Tools > Raster > Mosaic Dataset > Add Raster to Mosaic Dataset, which is the step that will allow us to shed all our minor rasters into the recently created geodatabase to create the final Mosaic.

To not get a massive file of 20 GB weight and burn out our computer, we went for a more manageable approach. So, we decided to split the total coastline of the Catalan Coast in 8 different zones, representing the following geographical/political areas of interest:

- Mosaic 1: Delta del Ebre
- Mosaic 2: Baix Camp and Tarragonés
- Mosaic 3: Baix Penedés and Garraf
- Mosaic 4: Baix Llobregat and Barcelonés
- Mosaic 5: Maresme
- Mosaic 6: La Selva
- Mosaic 7: Baix Empordà
- Mosaic 8: Alt Empordà

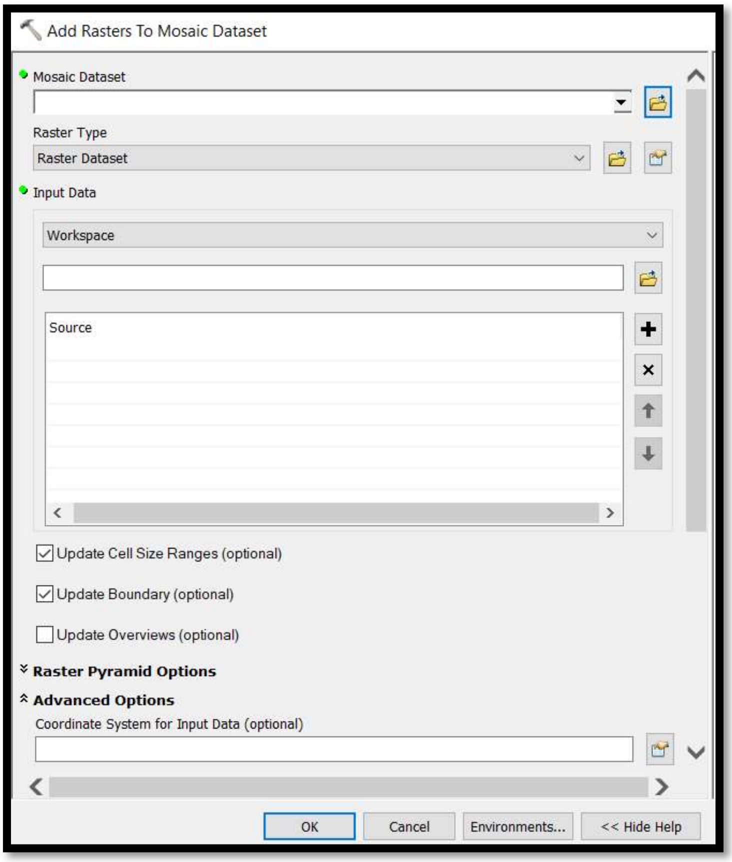



*Illustration 22. Add Rasters to Mosaic Dataset command window.*

Same as before, there are different parameters to select or set.

Mosaic Dataset is just the name and location of the 8 new files, that together will hold the full DEM of the Catalan litoral. The inputs are all the individual pieces of the mosaic that compose the totality of the designed area. Pixel type will be 32Bit Float again, as we described before, it's the one that fits better into the quality that we are looking for to get the job done.

For better precision and quality, we will also check the "Calculate Statistics", "Build Raster Pyramids" and "Build Thumbnails". These options add weight to the calculations but it also gives us a more realistic approach.

Once the program has calculated the mosaic, we will get the following map:

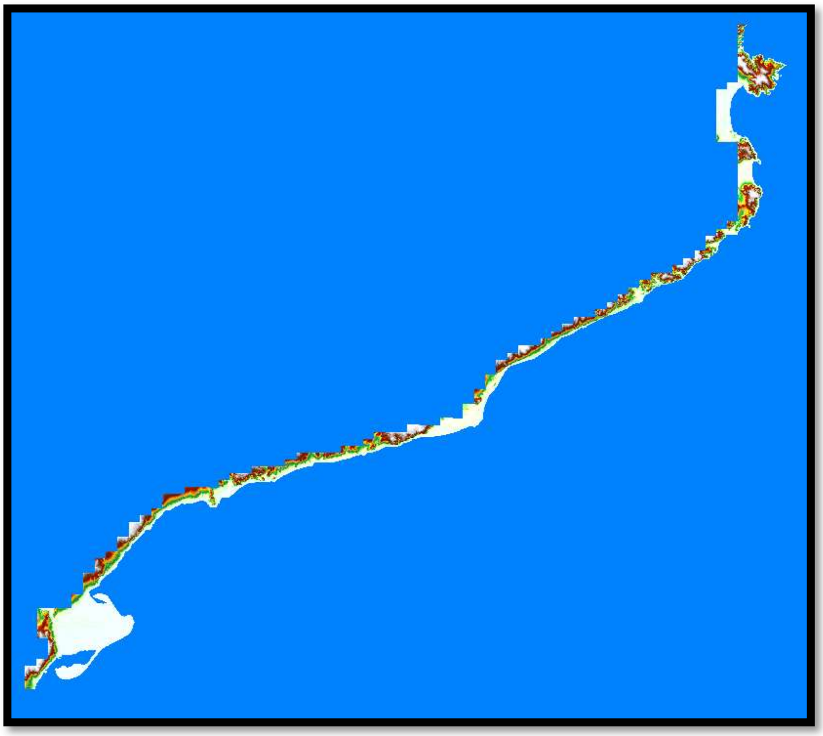


*Illustration 23. Our new one-piece DEM for the Catalan Coast.*

The annex number 1 presents the distinct 8 zones with a more detailed approach.

Optionally, once we unified all our DEM into the 8 zones, we can add other valuable information, like orthophotos (an aerial photograph or image geometrically corrected, such that the scale is uniform or in other words, the photo has the same lack of distortion as a map)[32] to help us identify the area of study easily.

We proceed once again to download the data from the ICC webpage and apply it to our current layer.

[32] (Wikipedia Cooperators, 2016)

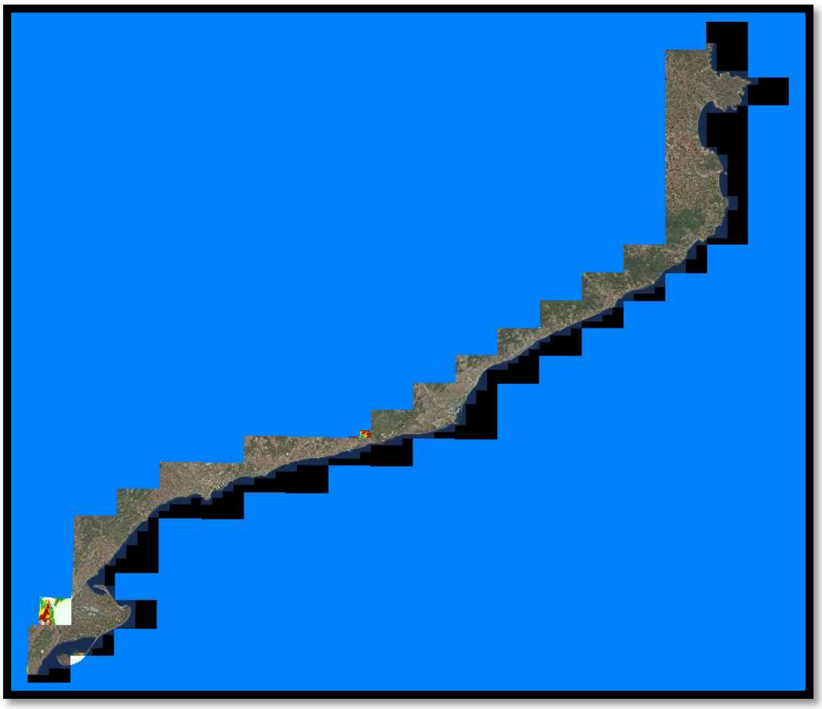


*Illustration 24. Raster plus Orthophotos of the Catalan Coast.*

Upon review of the new raster dataset numerous data gaps were observed. The data gaps represented areas that an inadequate number of radar return data points were present to accurately determine the bare earth elevation resulting in a null value assigned to the cell. Most of the data gaps occurred where bare earth returns could not be calculated such as building sites.

In order to correct this issue, we proceeded to fill the gaps with the Spatial Analyst Tools > Hydrology > Fill. It's a fantastic tool that automatically fills those gaps using elaborated mathematical formulas to calculate mean elevations from surrounding bits, and using it as the input value for the gap.

#### 2.4.2.2 Public Domain Maritime-Terrestrial Line

From the webpage of the "*Ministerio de agricultura y pesca, alimentación y medio ambiente"* we get the following:

"To promote effective protection of our coasts and to increase the legal security of rights holders on the coast, the demarcation lines of the entire Spanish coastline are published and free to download. After a long and laborious process, it has been possible to represent in digital format the line corresponding to the more than 10.000 Km of goods of the sea-land public domain the coast.

This achieves a double objective:

-Ensure transparency and information to citizens about their property and other rights, so that no citizen can ever buy a house or other property on the coast and later discover that it does not belong to him because it is DPMT.

-Establish effective protection on our coasts by making sure that all actors acting on the coast know clearly what goods are in the maritime-terrestrial public domain and what goods, even if they are private, are affected by limitations, inappropriate occupations that may affect a medium as sensitive as the coast."[33]
So, as it is stated, we will get data from which goods are in DPMT (Public Domain Maritime-Terrestrial Line) and are at possible risk in the future of being damaged.

*Illustration 25. Example of how DPMT works.*

As we can see in the example of this picture, the DPMT goes through different geographical elements, like cliffs, maritime promenades, public parkings and streets, different beach-based business (like ice-creams shops or sea food restaurants), apartments, a hotel and a small forest. Only this picture is strong enough to show how bad the consequences could be, having a big increase on sea level in the future combined with a strong seasonal storm. And this is only a small and "not so high" urbanized beach. The potential cost in euros for the damages could scale very easily to hundreds of millions if we consider bigger areas, like the Catalan coast.

In this study, the DPMT will serve us on purposes of identification of vulnerable areas. In other words, all those areas where the SLR breaches into the DPMT area, will be classified as vulnerable.

#### 2.4.2.3 Cover Map

Once we have prepared the base rasters, we are set to download the cover maps or, in other words, the map of land uses. We will need it to identify which critical land uses get more affected by the potential sea rise.

[33] (Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente., 2017)

The land uses cover map can be obtained from CREAF webpage, which stands for "Centre de Recerca Ecològica i Aplicacions Forestals". CREAF is a public research center dedicated to terrestrial ecology and territorial analysis, producing knowledge and methodologies for conservation, management, and adaptation of the environment to global change.[34]

From their free to use MCSC service (Mapa de Cobertes del Sòl de Catalunya) we can download the land uses map we are looking for. The data we had access to was created in 2009, on the 4th edition, which, despite being 8 years old, will still be useful, since no much has been constructed or modified along the coast during this years of economic crisis.

Similar to what happened with the rasters that we downloaded from ICGC, the map service of land uses was divided in multiple zones, which we patiently downloaded one by one, in shp. format.

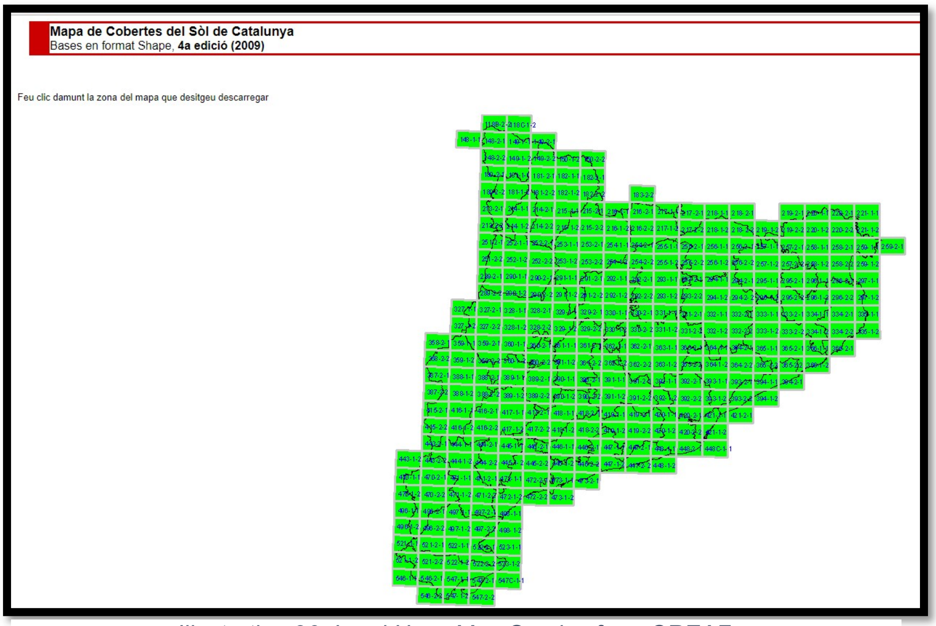



*Illustration 26. Land Uses Map Service from CREAF.*
*(http://www.creaf.uab.es/mcsc/map-mcscshp4.htm)*

Once we downloaded all the required coast squares, we are ready to apply it to our current model.

[34] (Universitat Autonoma de Barcelona & Generalitat de Catalunya, 2017)

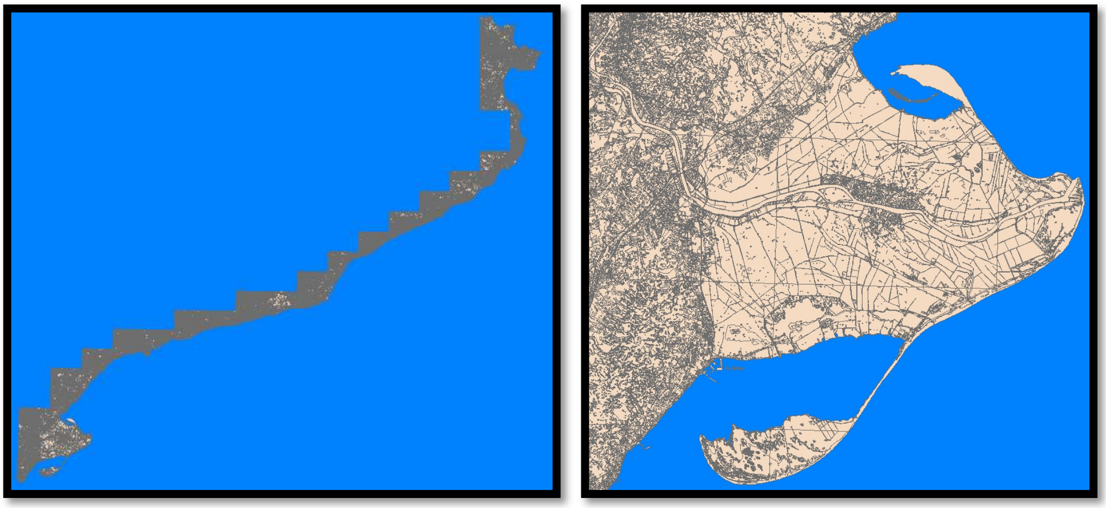


*Illustration 27. General View of the Coastal Land Uses and Detailed View of Ebre Delta Land Uses.*

Now we must merge all the single squares into a single piece of land use, this will help us to get a single chromatic scheme so we can identify better the distinct land uses. To do so we must selec all the different 72 squares and then apply the following command: Geoprocessing > Merge. Finally we will configurate our single land use map to show a diferent colour for each diferent land use.

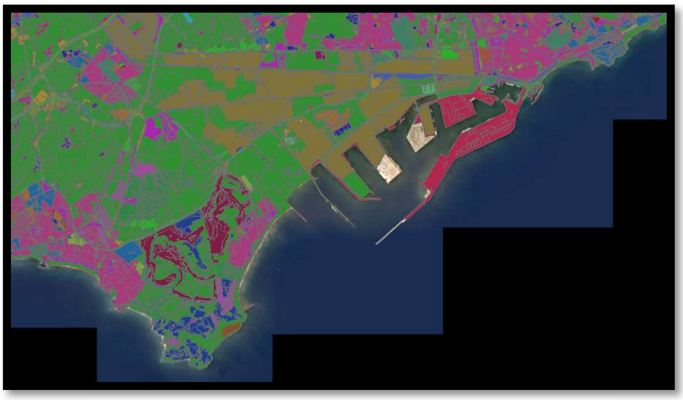


*Illustration 28. Detail of the different chromatic scheme applied to different land uses.*

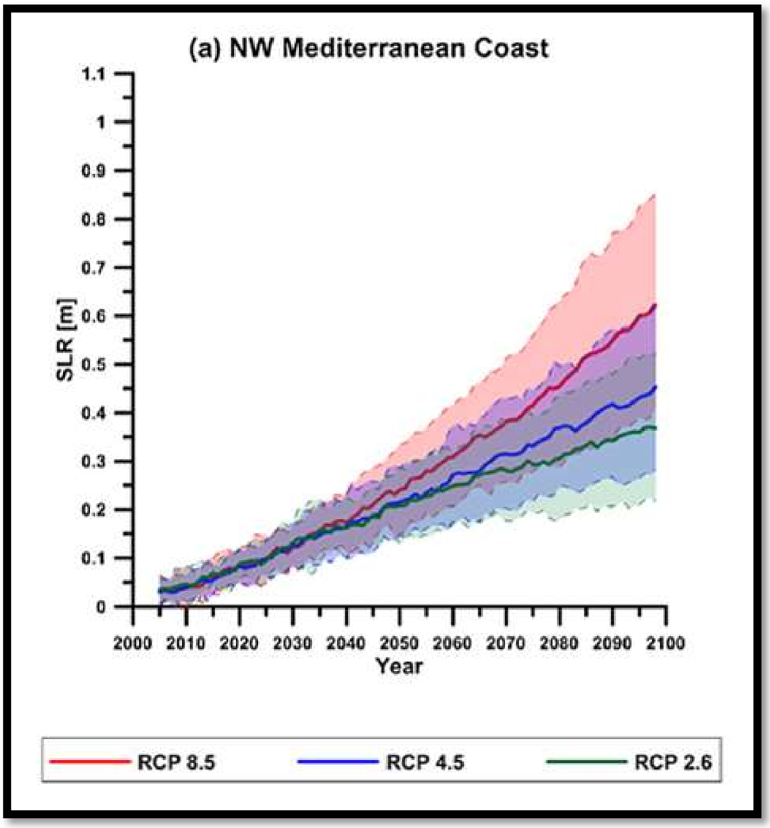
More detailed maps and their respective legends can be found on the annex 1.

From this map, we will extract information about the total area that every type of land occupies on our coast on the present date. We will use this data as our reference in the future operations.

### 2.4.3 Sea Level Rise Simulation

Once we have prepared the entirety of our coast raster, we are ready to apply the bathtub method.

We will use the data from ICCP that predicts different sea level rise possibilities depending on which RCP (Representative Concentration Pathways) scenario we are on, so that we can simulate an evolution of that case along the 21st century. The following table will express which are the values we calculated for:




*Graphic 1. RCP's possibilities for the XXI Century.*[35]

| Year/RCP SLR | 2,6 | 4,5 | 8,5 |
|---|---|---|---|
| 2025 | 0,10 m | 0,10 m | 0,10 m |
| 2050 | 0,20 m | 0,20 m | 0,21 m |
| 2075 | 0,30 m | 0,35 m | 0,42 m |
| 2100 | 0,42 m | 0,47 m | 0,61 m |

*Table 1. Different SLR values for different RCP scenarios.*[36]

Once we know the values we will have to use to calculate the SLR, we can proceed to develop our model. We will start with RCP 2,6, year by year, and then pass on to RCP 4,5 and so on.

The command we have to use in ArcGis for calculating the rise is the following: ArcToolbox > Spatial Analyst Tools > Math > Logical > Less than Equal.

The following window will appear:

[35] (IPCC, et al, 2014)
[36] (Sánchez-Arcilla, 2016)

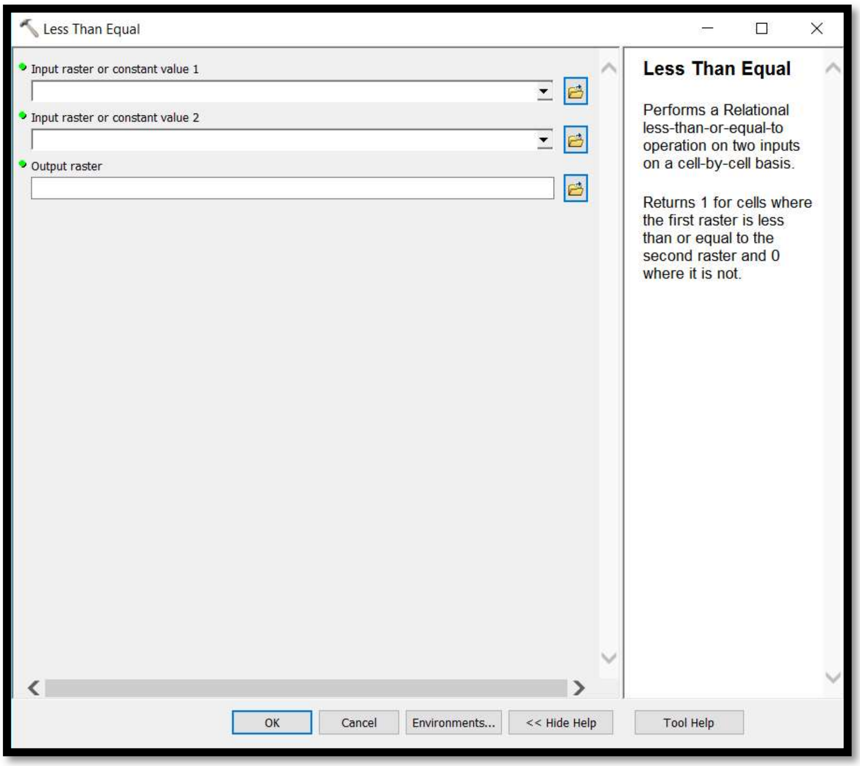



*Illustration 29. Command window for Less than Equal operation.*

On the first input, the base DEM which we want to subtract values from must be added and on the second input, we just add the value of SLR we want to calculate. The result will be another raster. The following example will give an approximate idea of what's the expected result.

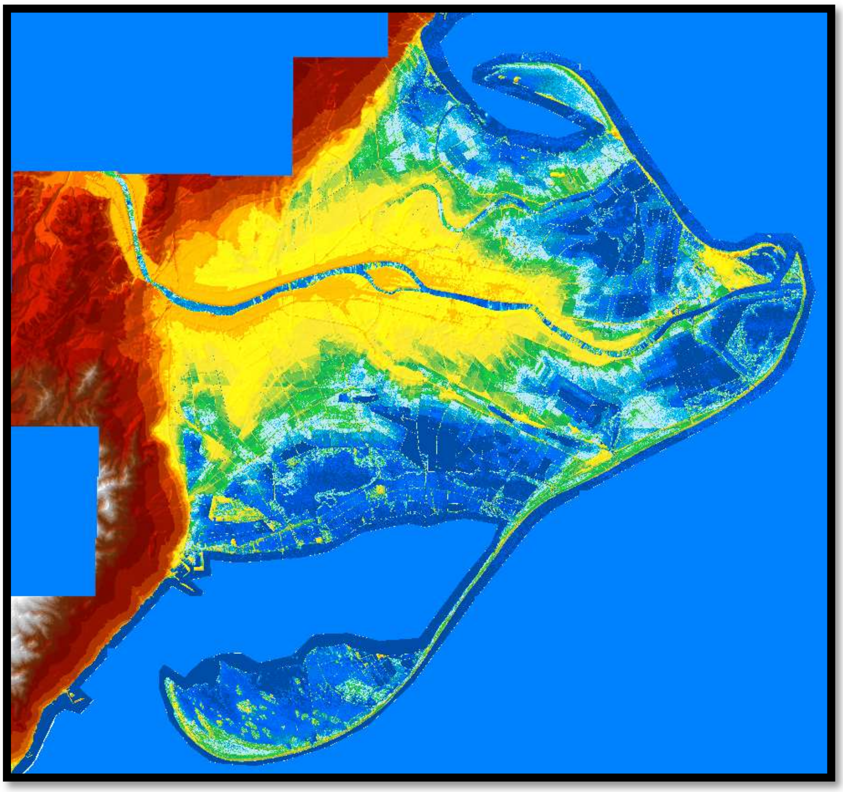


*Illustration 30. Delta del Ebre SLR simulation.*

We can easily observe the increase on the sea level in this pre-polygon conversion, where all the different blue shades embody the different phases of SLR on the 21st century. The darker shades represent the most immediate and probable flooded zones while the lighter zones are the most extreme cases. Be it one or the other, it's quite clear the massive impact it will have on the Delta. We shall now proceed to convert our new SLR into polygons to get more detailed information. The annex 1.2 provides detailed information on the different flooded zone by RCP's and chronological order.

### 2.4.3.1 Polygonization

Firstly, we must group together the same land uses type polygons, in order to calculate total areas. In order to do so we must start the editor, open the attribute table, and select all the same type polygons and proceed to merge them together. In doing so, we will pass from around two hundred thousand items to 50 groups of polygons, which will make our next steps much easier.

We will transform our SLR rasters, into polygons, in order to clip them with our land cover raster, and extract information about flooded areas by type of use. We can only do so if the files that we overlay with each other are polygon shp files, so that's why we must use this method.

The following command must be applied to our new SLR rasters; Arctoolbox > Conversion Tool > From Raster > Raster to Polygon. The following command window will appear.

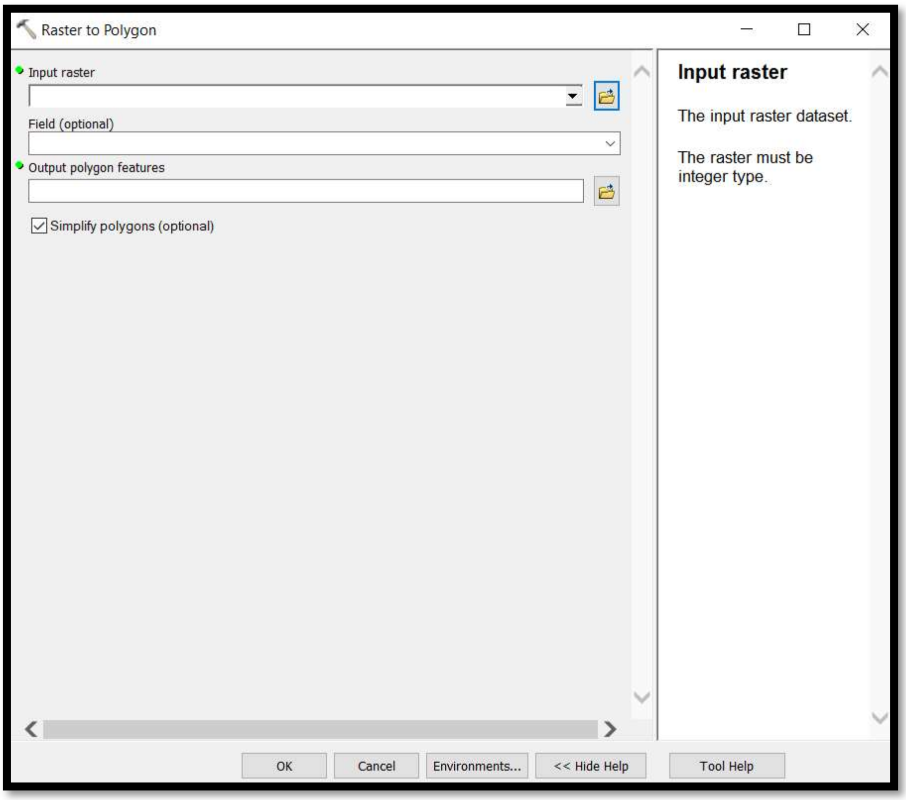



*Illustration 31. Raster to Polygon Command Window*

In the input raster, we must add our SLR raster, and we must specify the location of the new shp file (polygon) on the output. The field is the value we assign to every polygon.

There are only 2 values, 1 or 0. Value 1 equals to polygons under the new water level, while value 0 means polygons which will be over it. We are only interested on the value 1 polygons, so we will delete the others.

The following files were created (the number indicates the expected SLR in centimeters):

- Polygon form 010
- Polygon form 020
- Polygon form 030
- Polygon form 035
- Polygon form 042
- Polygon form 047
- Polygon form 061

The next step is to identify which polygons will be affected by a hypothetic SLR value.

In order to do so, we must apply a Clip command; Analyst Tools > Extract > Clip. The following window will appear:

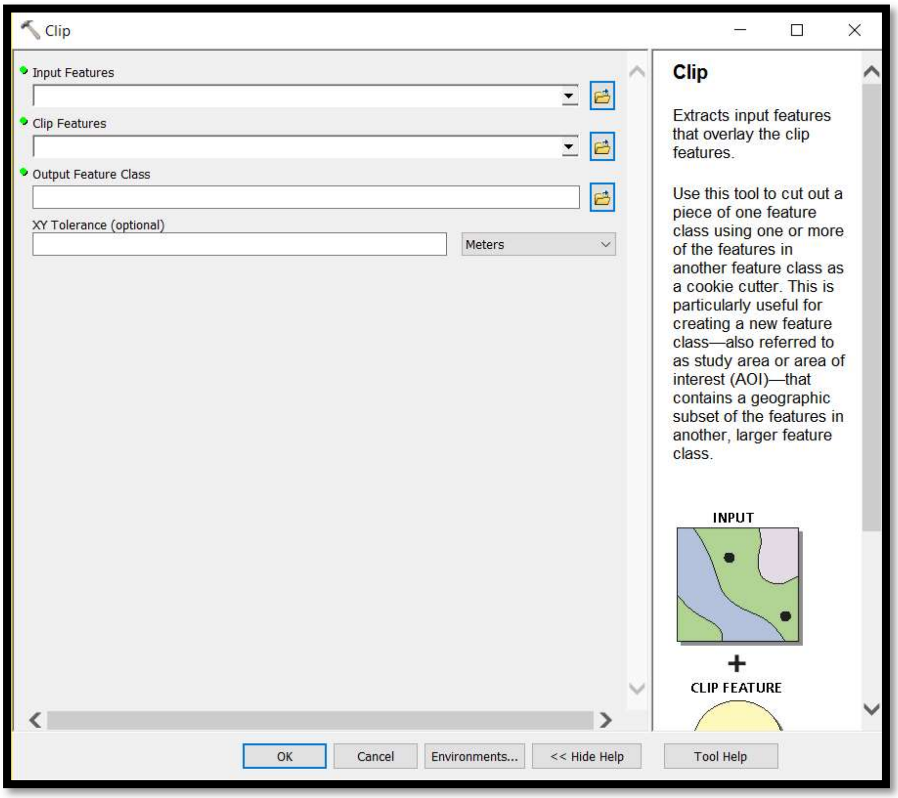
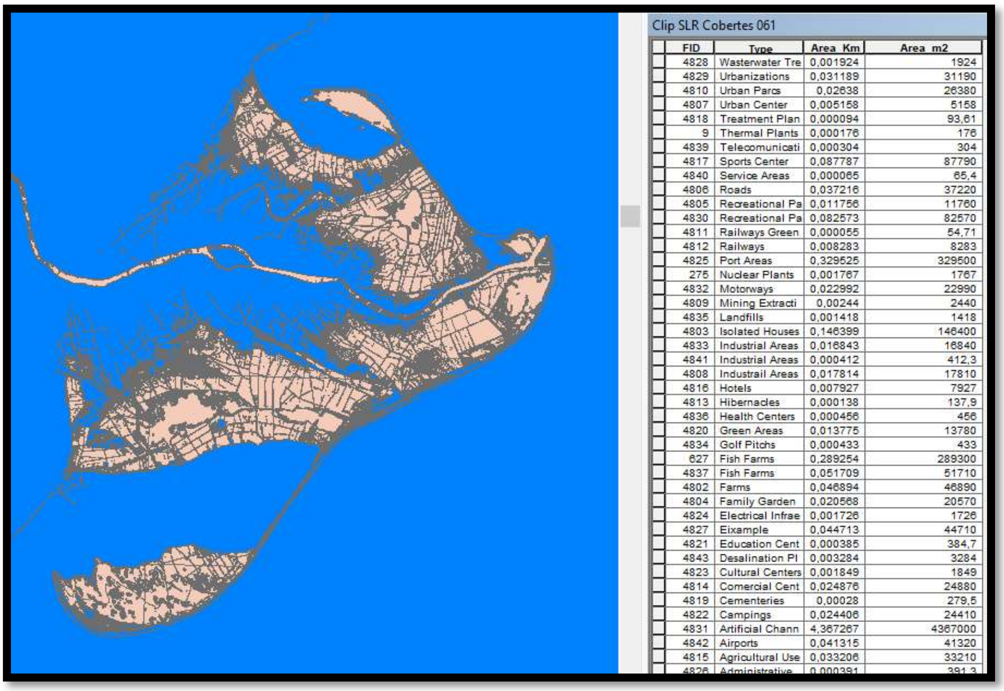



*Illustration 32. Clip Command Window*

The input feature, will be our land cover raster, while the clip feature will be our polygonised SLR raster. The output will be land cover uses affected by the specific SLR, in a polygon shapefile. In other words, the final result of the scope of this study.



Clip SLR Cobertes 061

| FID | Type | Area_Km | Area_m2 |
|---|---|---|---|
| 4828 | Wasterwater Tre | 0,001924 | 1924 |
| 4829 | Urbanizations | 0,031189 | 31190 |
| 4810 | Urban Parcs | 0,02638 | 26380 |
| 4807 | Urban Center | 0,005158 | 5158 |
| 4818 | Treatment Plan | 0,000094 | 93,61 |
| 9 | Thermal Plants | 0,000176 | 176 |
| 4839 | Telecomunicati | 0,000304 | 304 |
| 4817 | Sports Center | 0,087787 | 87790 |
| 4840 | Service Areas | 0,000065 | 65,4 |
| 4806 | Roads | 0,037216 | 37220 |
| 4805 | Recreational Pa | 0,011756 | 11760 |
| 4830 | Recreational Pa | 0,082573 | 82570 |
| 4811 | Railways Green | 0,000055 | 54,71 |
| 4812 | Railways | 0,008283 | 8283 |
| 4825 | Port Areas | 0,329525 | 329500 |
| 275 | Nuclear Plants | 0,001767 | 1767 |
| 4832 | Motorways | 0,022992 | 22990 |
| 4809 | Mining Extracti | 0,00244 | 2440 |
| 4835 | Landfills | 0,001418 | 1418 |
| 4803 | Isolated Houses | 0,146399 | 146400 |
| 4833 | Industrial Areas | 0,016843 | 16840 |
| 4841 | Industrial Areas | 0,000412 | 412,3 |
| 4808 | Industrail Areas | 0,017814 | 17810 |
| 4816 | Hotels | 0,007927 | 7927 |
| 4813 | Hibernacles | 0,000138 | 137,9 |
| 4836 | Health Centers | 0,000456 | 456 |
| 4820 | Green Areas | 0,013775 | 13780 |
| 4834 | Golf Pitchs | 0,000433 | 433 |
| 627 | Fish Farms | 0,289254 | 289300 |
| 4837 | Fish Farms | 0,051709 | 51710 |
| 4802 | Farms | 0,046894 | 46890 |
| 4804 | Family Garden | 0,020568 | 20570 |
| 4824 | Electrical Infrae | 0,001726 | 1726 |
| 4827 | Eixample | 0,044713 | 44710 |
| 4821 | Education Cent | 0,000385 | 384,7 |
| 4843 | Desalination Pl | 0,003284 | 3284 |
| 4823 | Cultural Centers | 0,001849 | 1849 |
| 4814 | Comercial Cent | 0,024876 | 24880 |
| 4819 | Cementeries | 0,00028 | 279,5 |
| 4822 | Campings | 0,024406 | 24410 |
| 4831 | Artificial Chann | 4,367267 | 4367000 |
| 4842 | Airports | 0,041315 | 41320 |
| 4815 | Agricultural Use | 0,033206 | 33210 |
| 4826 | Administrative | 0,000391 | 391,3 |

*Illustration 33. Example of Polygon Shp of Land Cover Uses by an estimated Sea Level Rise in Ebre Delta.*

As we can see in this example, all the polygons affected by a given SLR input, are listed and their total areas calculated, and classified by type. More detailed results will be added to the results section and the annexes of this study.

## 2.5 Vulnerabilities Identification

Once all the calculation process is finished, we proceed to identify possible vulnerabilities with a general look. By vulnerabilities, we identify such areas where the Sea Level Rise prompts a breach into the **Land Maritime Public Domain.**

### 2.5.1 General vulnerabilities

There will be a considerable amount of sea water penetrating upward from river deltas and stream openings. There will be, as well, a salinization of the underground water alongside it. This effect will increase greatly from 2050 onwards.

There will be a generalized withdrawal from the coastline to all the beaches, paying special attention to the beaches with the lowest slope. A significant increase of this effect will take place as well as of 2050.

### 2.5.2 Specific Vulnerabilities

Until 2050 there will some areas that deserve special attention (apart from the general areas specified above), those areas being the river deltas of *Fluvià, Ter,* *Besòs, Llobregat* and *Ebre*. There is a more detailed and graphic description in the annexes 5.1.2.

From 2050 onwards, more areas needing special attention will be added, like the *Empuriabrava* artificial channels and ponds, the wetlands of *Aiguamolls del Empordà*, the rafts of *Basses d'en Coll*, river delta of *La Tordera*, the airport of *El Prat* and surrounding wetlands, *Cap de Sant Pere* and the river delta of *El Foix*.

Without doubt, many other locations and land uses will be affected, though, in less extent. Nevertheless, all of the areas affected by SLR will be mentioned despite the extension of those affections, in the results section of this study.

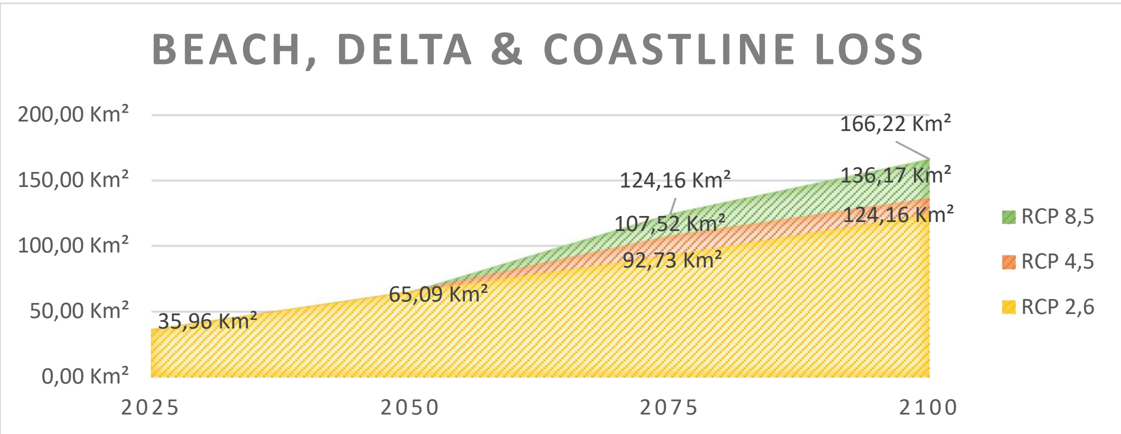
## 3. Results

In this section, we are going to present the general results of this study. There will be detailed graphics in the annexes, 5.1.3.

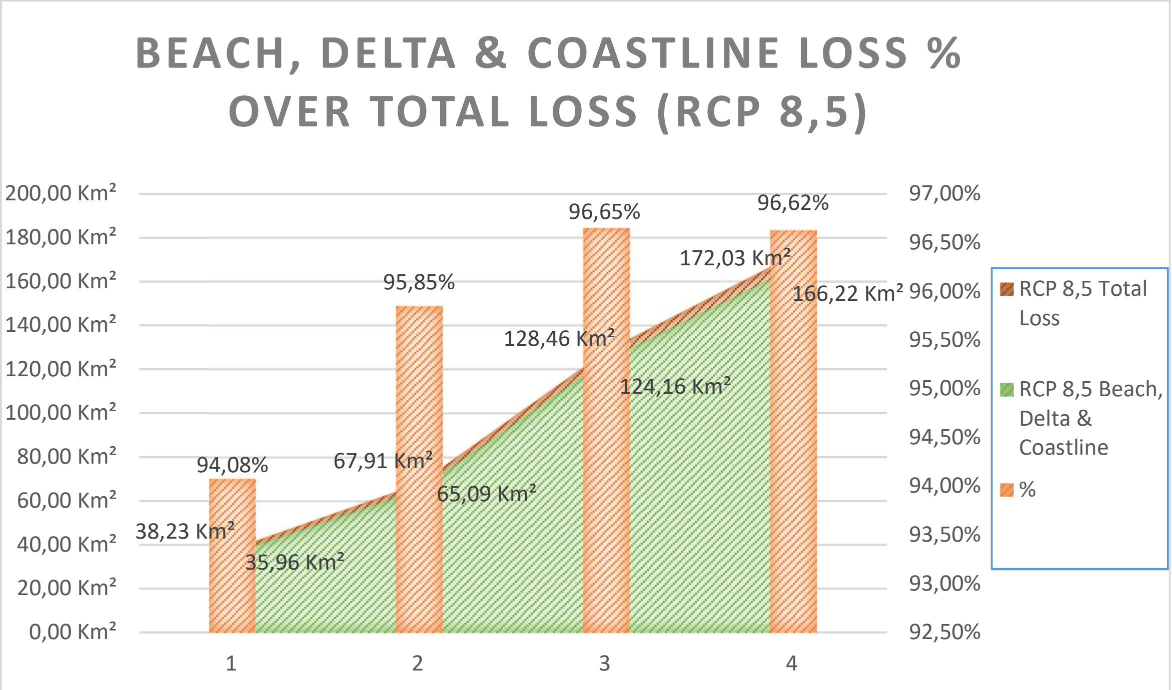
The following graph describes the general loss of terrain, in the different scenarios contemplated in the study. As we can see, this first part of the century there is no much difference between the Representative Concentration Pathways, but clearly diverge from 2050 onwards, the trend being linear at first glance, but on different magnitude of slopes on the 3 paths.


Graphic 2. Total Loss of Terrain

The biggest part of the loss of terrain comes from beaches and river deltas, specially Ebre delta. These particular land zones will act as shields during this century, protecting other land uses that are closer to the coastline, so it is elementary to think that they will take the biggest blow.




Graphic 3. Beach, Delta & Coastline Loss.




*Graphic 4. Beach, Delta & Coastline Loss % Over Total Loss (RCP 8,5).*

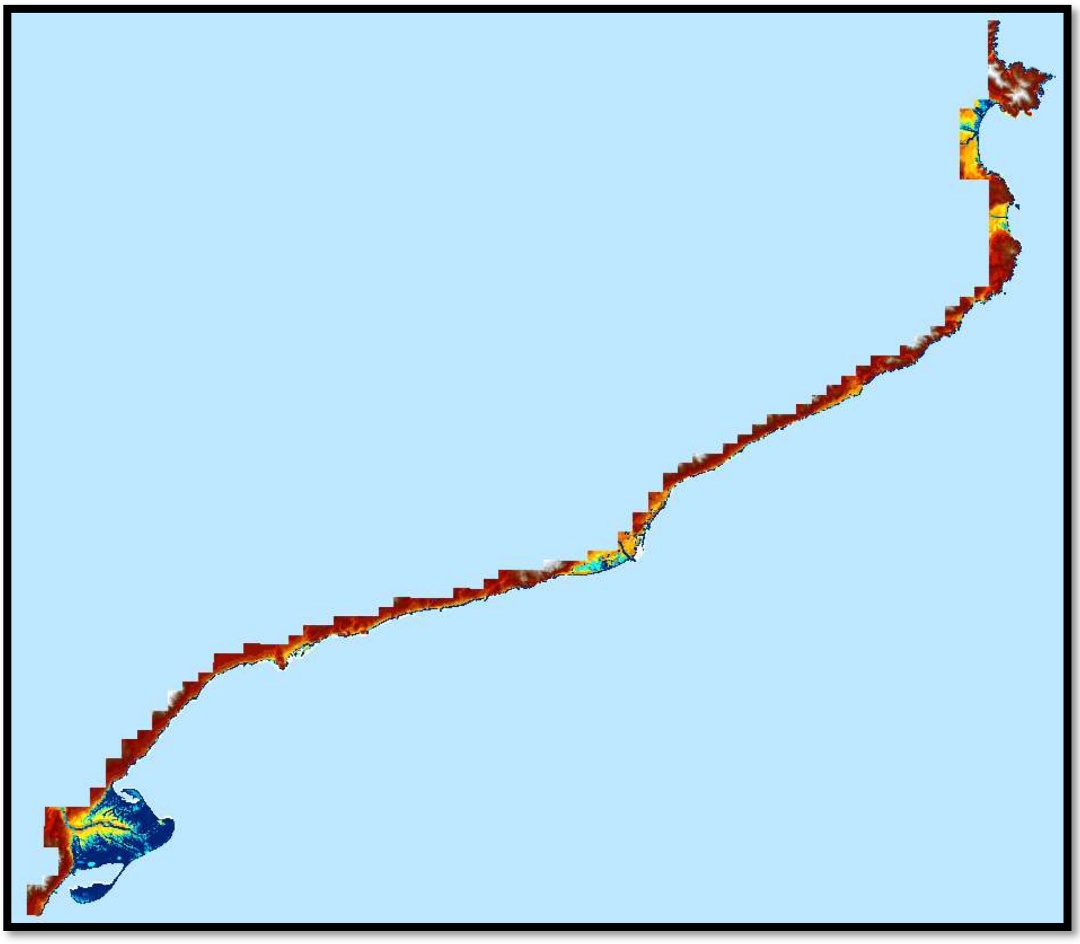
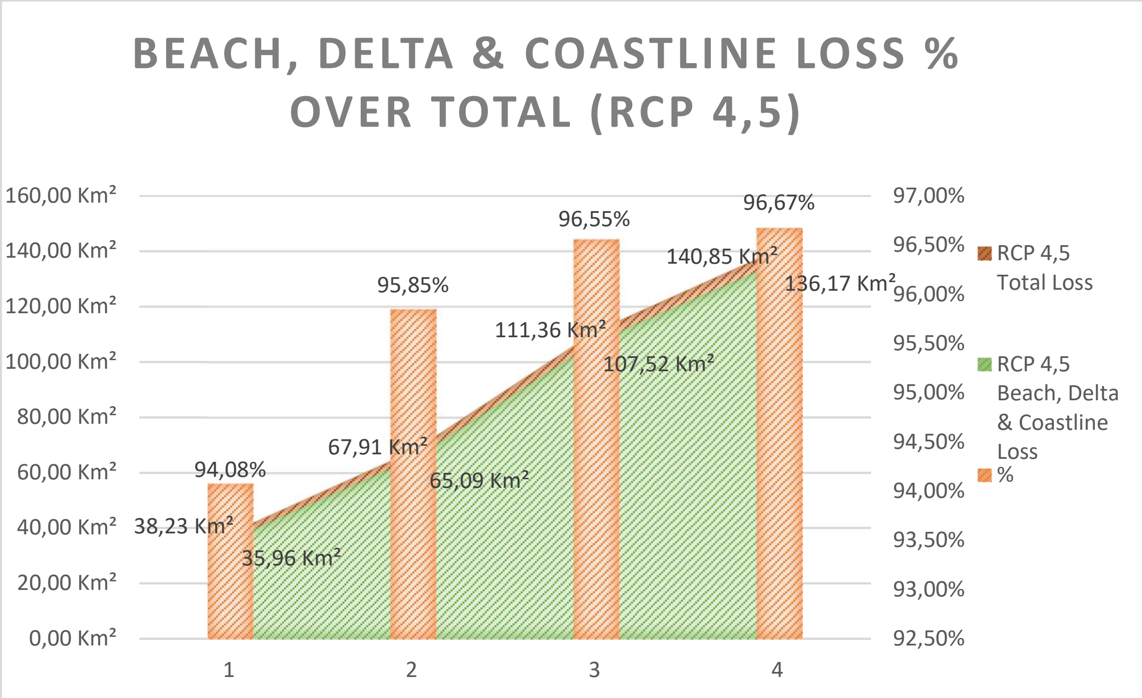


*Illustration 34. RCP 8,5 Sea Level Rise Scenario (2010-2100)*




*Graphic 5. Beach, Delta & Coastline Loss % Over Total Loss (RCP 4,5).*

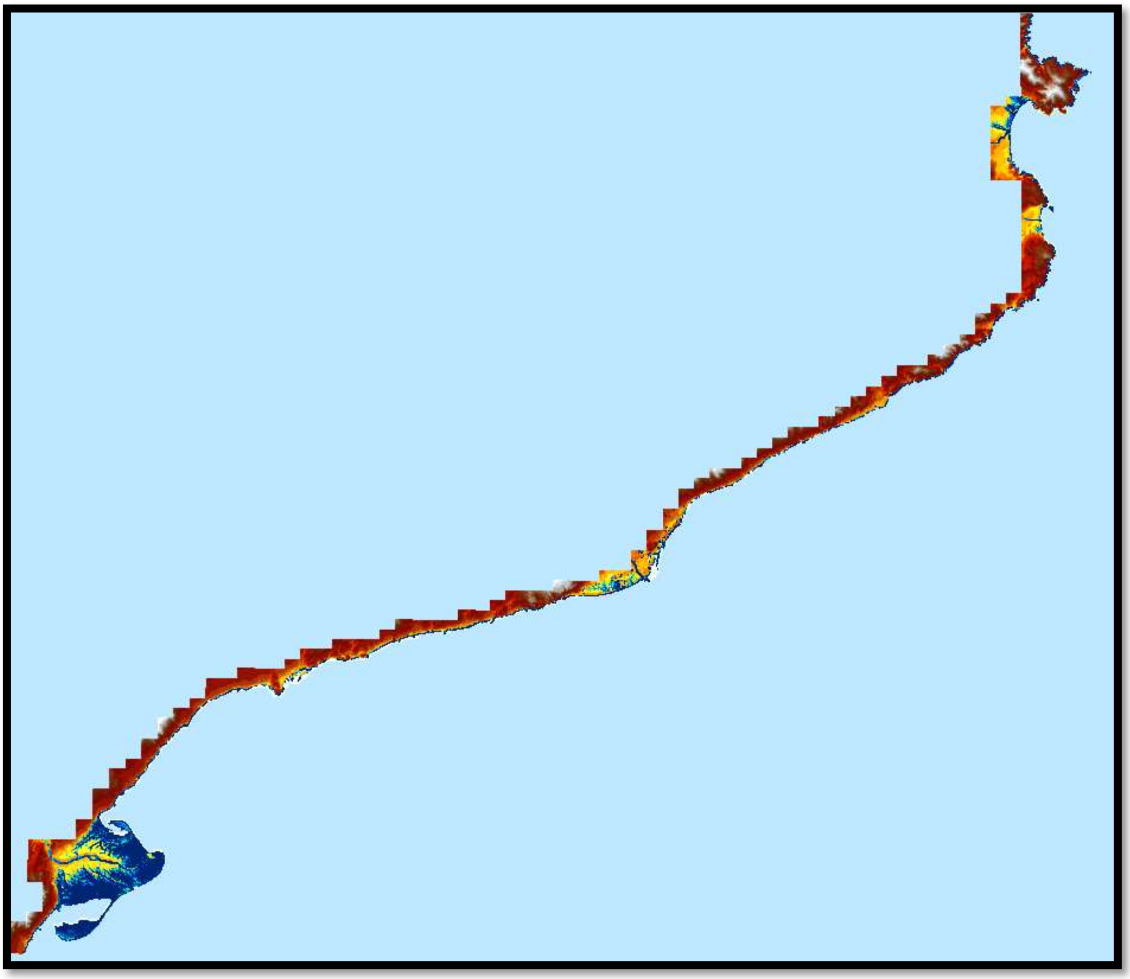
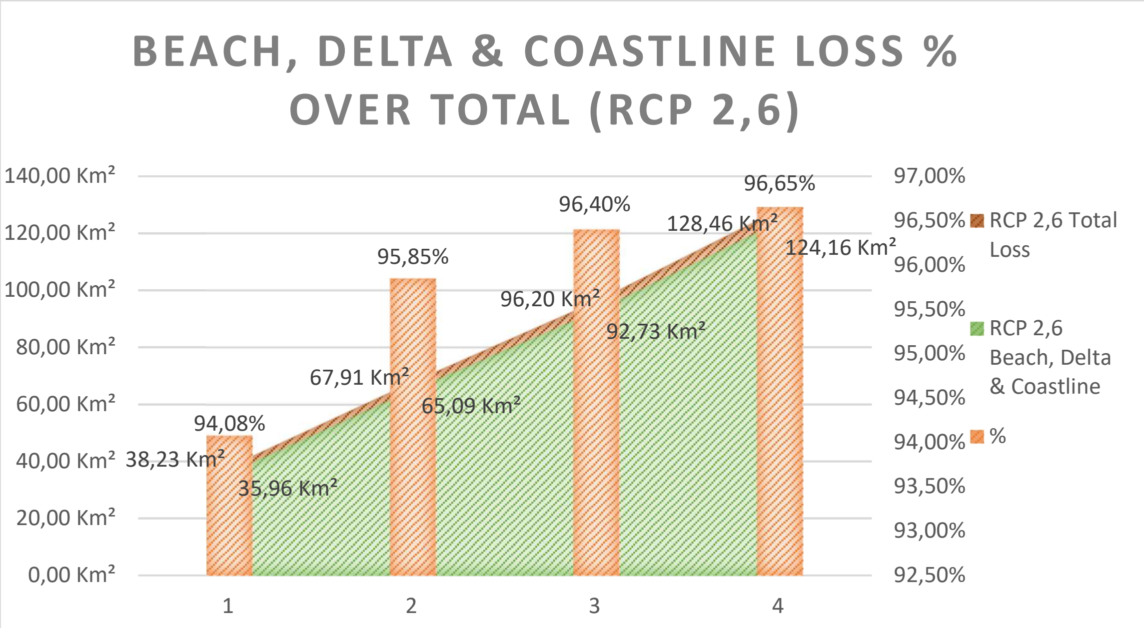


*Illustration 35. RCP 4,5 Sea Level Rise Scenario (2010-2100)*




Graphic 6. Beach, Delta & Coastline Loss % Over Total Loss (RCP 2,6)

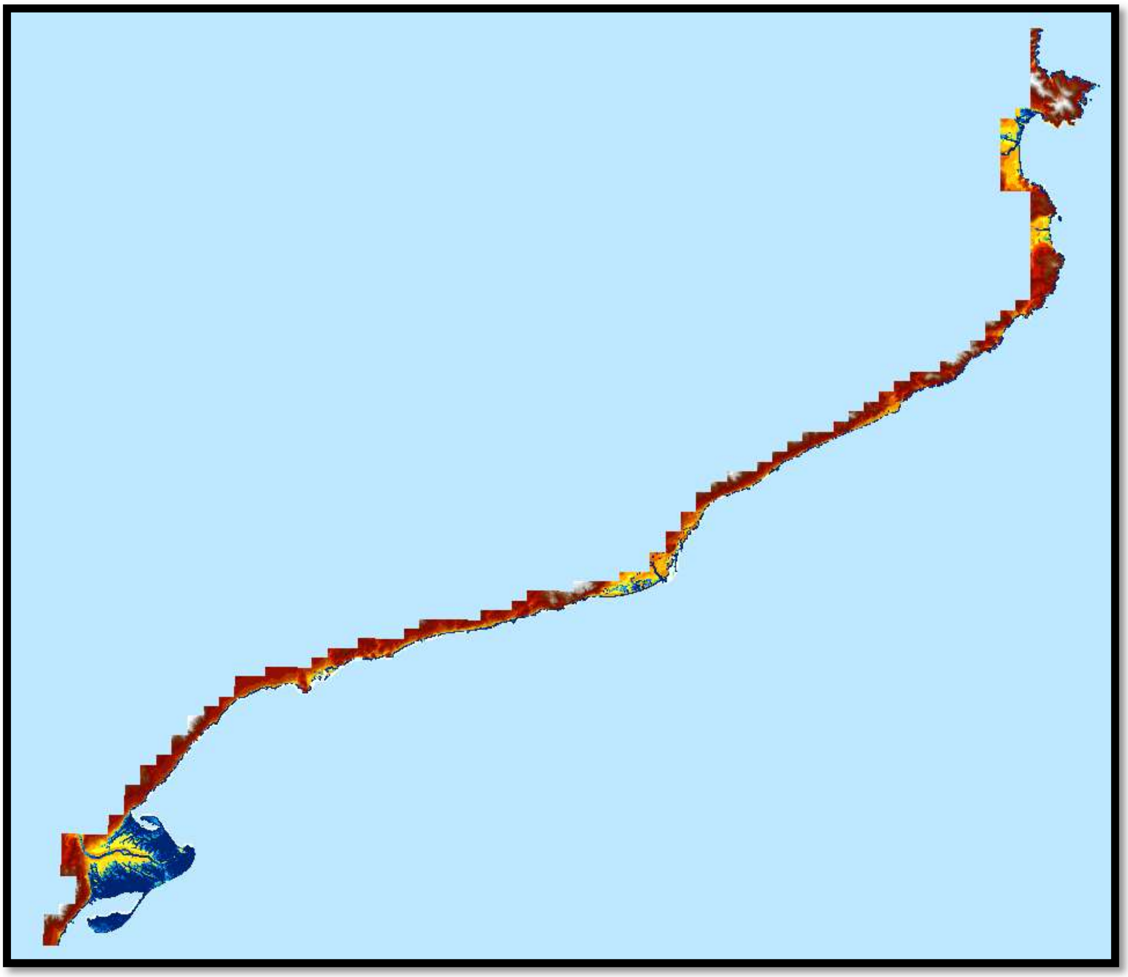


Illustration 36. RCP 2,6 Sea Level Rise Scenario (2010-2100)

As we can see, in all the presented paths, the loss of beach, coastline and delta represents around 95% of the total loss at any given time and scenario. The most vulnerable areas we can identify are: **Ebre Delta, Port Ginesta- El Prat del Llobregat, l'Estartit** and **Roses Gulf.**

Now we will proceed to analyze the **worst-case scenario (RCP 8,5)**, by coastal sections, vulnerable areas and municipalities by the **year 2100**.

## 3.1 Littoral Cells

There are 22 recognized sections by the government of Catalonia in the Catalan Coast[37]. We are going to give some in depth detail of what to expect on every single one of those sections on the year 2100 on the worst possible scenario.

For this reason, we will have to define the 22 sections in polygons, in order to be able to cross the information with the uses of the soil.

The following graphics and tables expose the results of clipping thos 22 polygons with land uses polygon we obtained in 2.4.3.1.

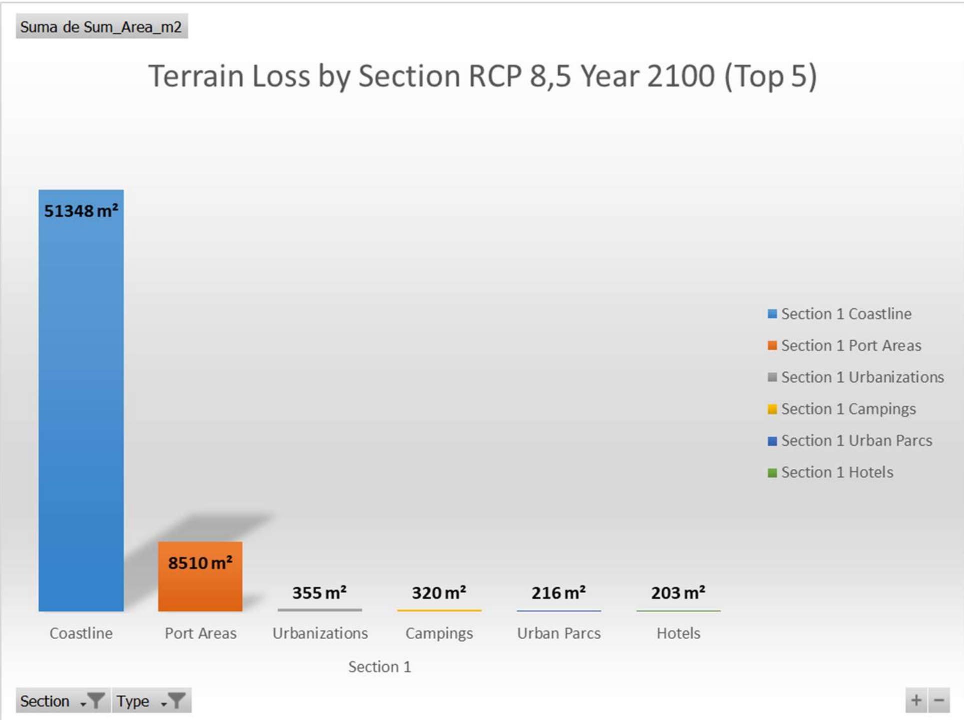
### 3.1.1 Littoral Cell 1. River Senia – Port St Carles de la Rapita.

*Illustration 37. Section 1 (2100, RCP 8,5).*

[37] (Institut Cartogràfic i Geològic de Catalunya, 2010)

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 1 | Natural Uses* | 0,05 Km² | 51348 m² |
| | Port Areas | 0,01 Km² | 8510 m² |
| | Urbanizations | 0,00 Km² | 355 m² |
| | Campings | 0,00 Km² | 320 m² |
| | Urban Parks | 0,00 Km² | 216 m² |
| | Hotels | 0,00 Km² | 203 m² |

*Table 2. Section 1 Loss (2100, RCP 8,5).*




*Graphic 7. Section 1 (2100, RCP 8,5).*

*Natural Uses: Includes Beaches, Forests, Fields and other natural uses.

### 3.1.2 Littoral Cell 2. Ebre Delta.

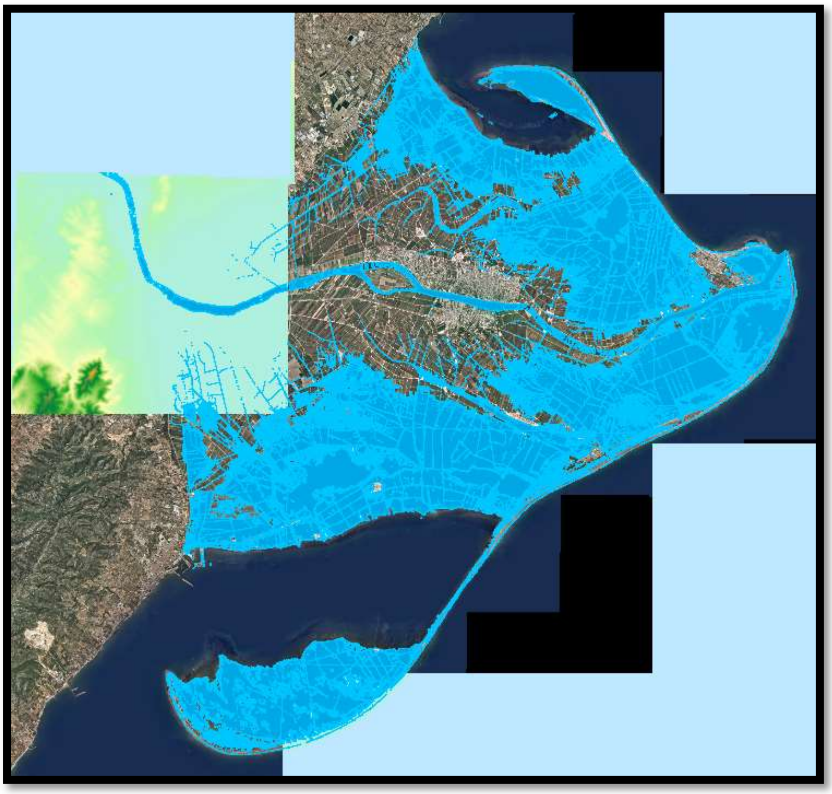
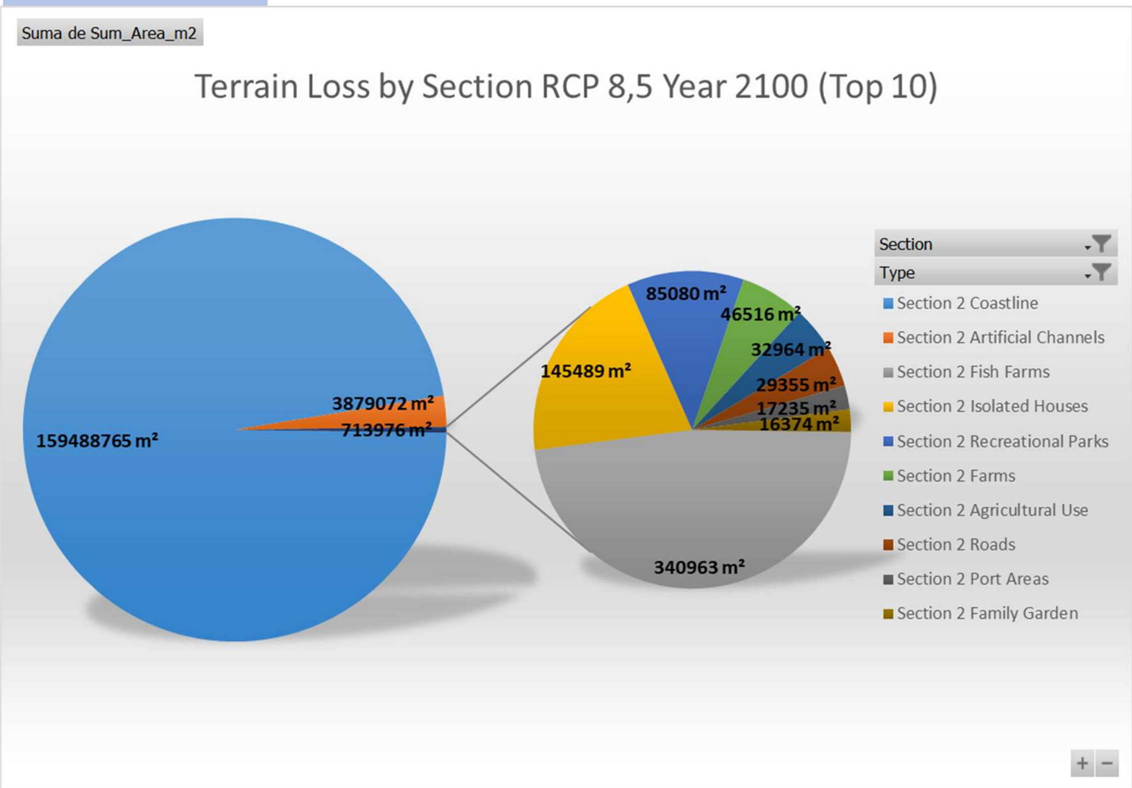


*Illustration 38. Section 2 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 2 | Natural Uses* | 159,49 Km² | 159488765 m² |
| | Artificial Channels | 3,88 Km² | 3879072 m² |
| | Fish Farms | 0,34 Km² | 340963 m² |
| | Isolated Houses | 0,15 Km² | 145489 m² |
| | Recreational Parks | 0,09 Km² | 85080 m² |
| | Farms | 0,05 Km² | 46516 m² |
| | Agricultural Use | 0,03 Km² | 32964 m² |
| | Roads | 0,03 Km² | 29355 m² |
| | Port Areas | 0,02 Km² | 17235 m² |
| | Family Garden | 0,02 Km² | 16374 m² |
| | Urban Parks | 0,01 Km² | 11837 m² |
| | Urbanizations | 0,01 Km² | 11205 m² |
| | Sports Center | 0,01 Km² | 11094 m² |
| | Green Areas | 0,01 Km² | 8993 m² |
| | Industrial Areas | 0,01 Km² | 8459 m² |
| | Motorways | 0,01 Km² | 6421 m² |
| | Campings | 0,00 Km² | 2815 m² |

| | | | |
|---|---|---|---|
| | Mining Extraction Areas | 0,00 Km² | 2440 m² |
| | Landfills | 0,00 Km² | 1397 m² |
| | Cultural Centers | 0,00 Km² | 1324 m² |
| | Urban Center | 0,00 Km² | 1139 m² |
| | Railways | 0,00 Km² | 851 m² |
| | Commercial Centers | 0,00 Km² | 396 m² |
| | Eixample | 0,00 Km² | 380 m² |
| | Cementeries | 0,00 Km² | 279 m² |
| | Electrical Infraestructures | 0,00 Km² | 306 m² |
| | Administrative Centers | 0,00 Km² | 219 m² |
| | Hotels | 0,00 Km² | 191 m² |
| | Golf Pitchs | 0,00 Km² | 132 m² |
| | Wastewater Treatment Plants | 0,00 Km² | 71 m² |
| | Hibernacles | 0,00 Km² | 17 m² |
| | Treatment Plants | 0,00 Km² | 12 m² |

Table 3. Section 2 Loss (2100, RCP 8,5).




Graphic 8. Section 2 (2100, RCP 8,5).

### 3.1.3 Littoral Cell 3. Ampolla – Port Vandellos Hospitalet Infant.

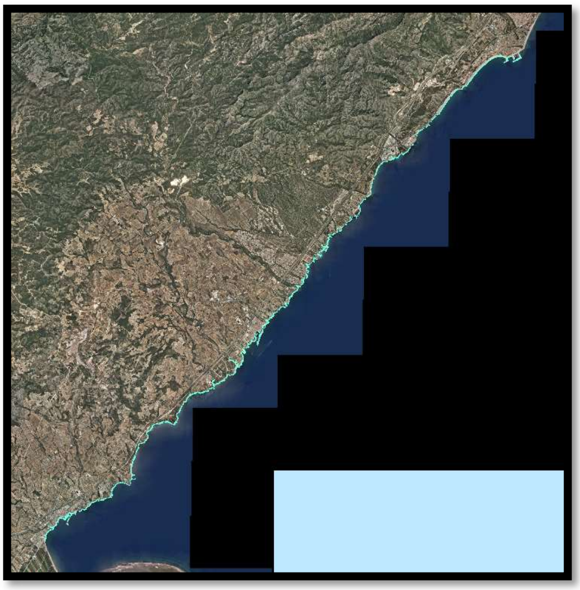
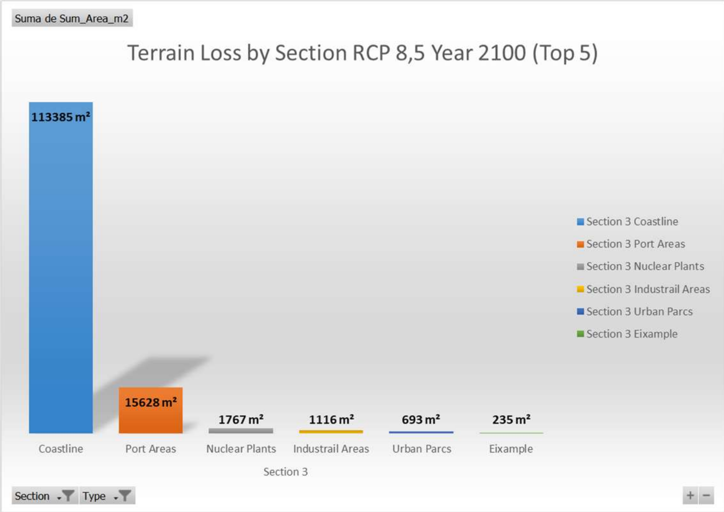


*Illustration 39. Section 3 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 3 | Natural Uses* | 0,11 Km² | 113385 m² |
| | Port Areas | 0,02 Km² | 15628 m² |
| | Nuclear Plants | 0,00 Km² | 1767 m² |
| | Industrial Areas | 0,00 Km² | 1116 m² |
| | Urban Parks | 0,00 Km² | 693 m² |
| | Eixample | 0,00 Km² | 235 m² |
| | Urbanizations | 0,00 Km² | 175 m² |
| | Urban Center | 0,00 Km² | 51 m² |
| | Recreational Parks | 0,00 Km² | 8 m² |

*Table 4. Section 3 Loss (2100, RCP 8,5).*



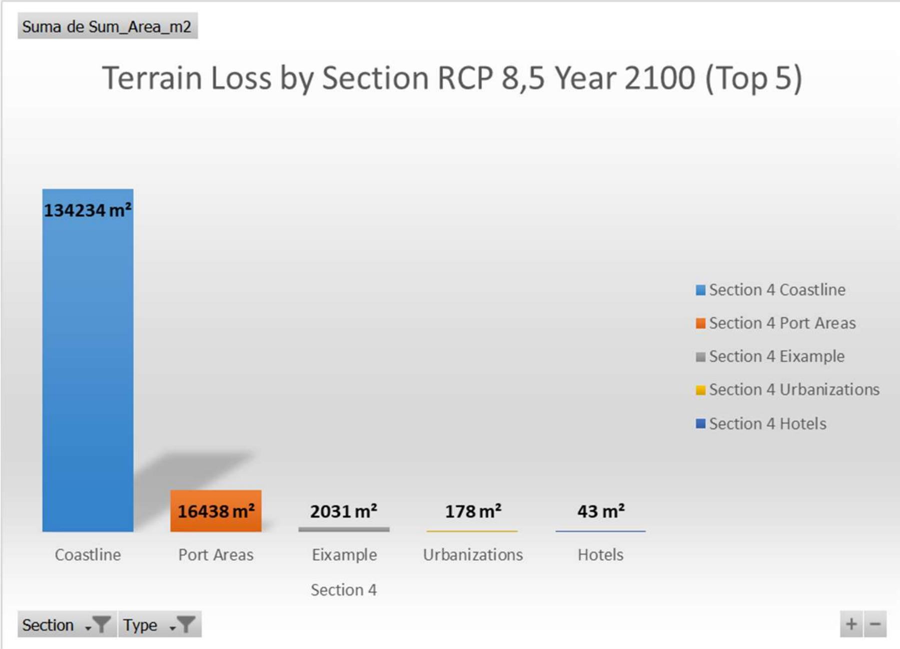

Graphic 9. Section 3 (2100, RCP 8,5).

### 3.1.4 Littoral Cell 4. Port Vandellos Hospitalet Infant – Salou.

Illustration 40. Section 4 (2100, RCP 8,5).

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 4 | Natural Uses* | 0,13 Km² | 134234 m² |
| | Port Areas | 0,02 Km² | 16438 m² |
| | Eixample | 0,00 Km² | 2031 m² |
| | Urbanizations | 0,00 Km² | 178 m² |
| | Hotels | 0,00 Km² | 43 m² |
| | Recreational Parks | 0,00 Km² | 5 m² |

Table 5. Section 4 Loss (2100, RCP 8,5).




*Graphic 10.Section 4 (2100, RCP 8,5).*

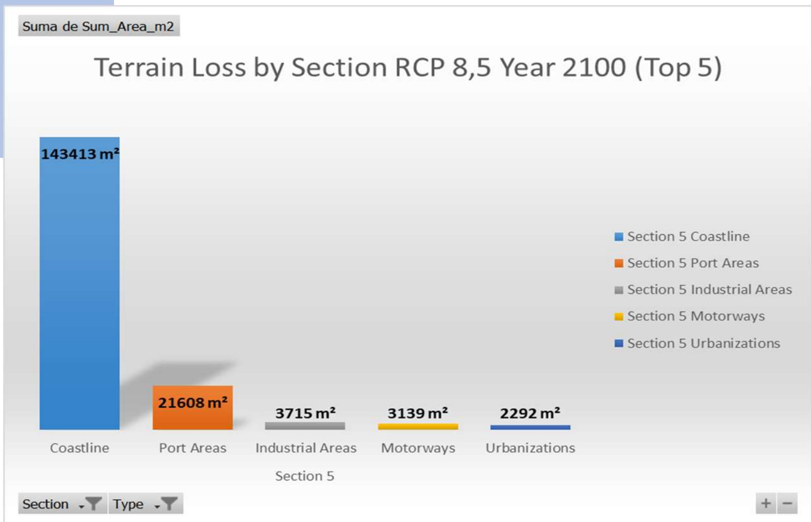
### 3.1.5 Littoral Cell 5. Vilaseca – Port Torredembarra

*Illustration 41.Section 5 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 5 | Natural Uses* | 0,14 Km² | 143413 m² |
| | Port Areas | 0,02 Km² | 21608 m² |
| | Industrial Areas | 0,00 Km² | 3715 m² |
| | Motorways | 0,00 Km² | 3139 m² |
| | Urbanizations | 0,00 Km² | 2292 m² |
| | Eixample | 0,00 Km² | 418 m² |
| | Education Centers | 0,00 Km² | 248 m² |
| | Campings | 0,00 Km² | 227 m² |

| | | | |
|---|---|---|---|
| | Railways | 0,00 Km² | 196 m² |
| | Golf Pitchs | 0,00 Km² | 180 m² |
| | Recreational Parks | 0,00 Km² | 104 m² |
| | Urban Parks | 0,00 Km² | 88 m² |
| | Green Areas | 0,00 Km² | 35 m² |
| | Commercial Centers | 0,00 Km² | 19 m² |
| | Wastewater Treatment Plants | 0,00 Km² | 15 m² |

*Table 6. Section 5 Loss (2100, RCP 8,5).*



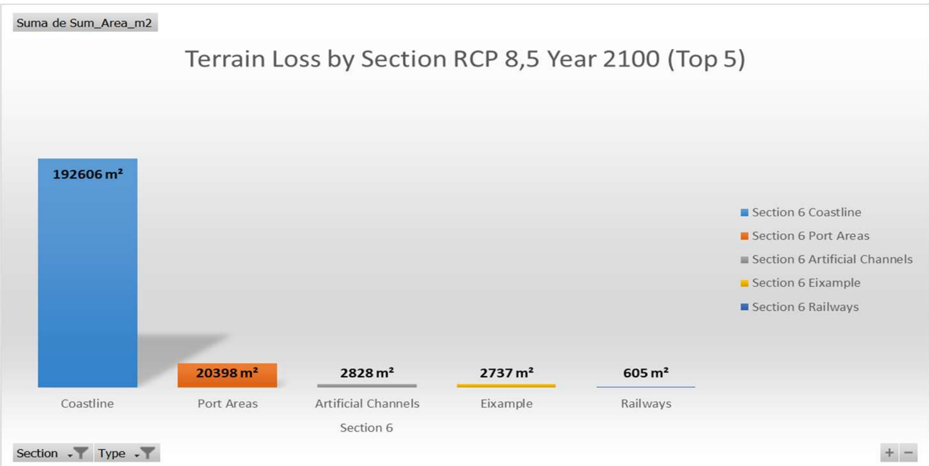

*Graphic 11. Section 5 (2100, RCP 8,5).*

### 3.1.6 Littoral Cell 6. Port Torredembarra – Central Tèrmica Cubelles.

*Illustration 42. Section 6 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 6 | Natural Uses* | 0,19 Km² | 192606 m² |
| | Port Areas | 0,02 Km² | 20398 m² |
| | Artificial Channels | 0,00 Km² | 2828 m² |
| | Eixample | 0,00 Km² | 2737 m² |
| | Railways | 0,00 Km² | 605 m² |
| | Health Centers | 0,00 Km² | 456 m² |
| | Commercial Centers | 0,00 Km² | 272 m² |
| | Thermal Plants | 0,00 Km² | 176 m² |
| | Urban Center | 0,00 Km² | 151 m² |
| | Industrial Areas | 0,00 Km² | 120 m² |
| | Recreational Parks | 0,00 Km² | 87 m² |
| | Sports Center | 0,00 Km² | 60 m² |
| | Hotels | 0,00 Km² | 11 m² |
| | Roads | 0,00 Km² | 4 m² |
| | Urban Parks | 0,00 Km² | 1 m² |
| | Urbanizations | 0,00 Km² | 1 m² |

*Table 7. Section 6 Loss (2100, RCP 8,5).*



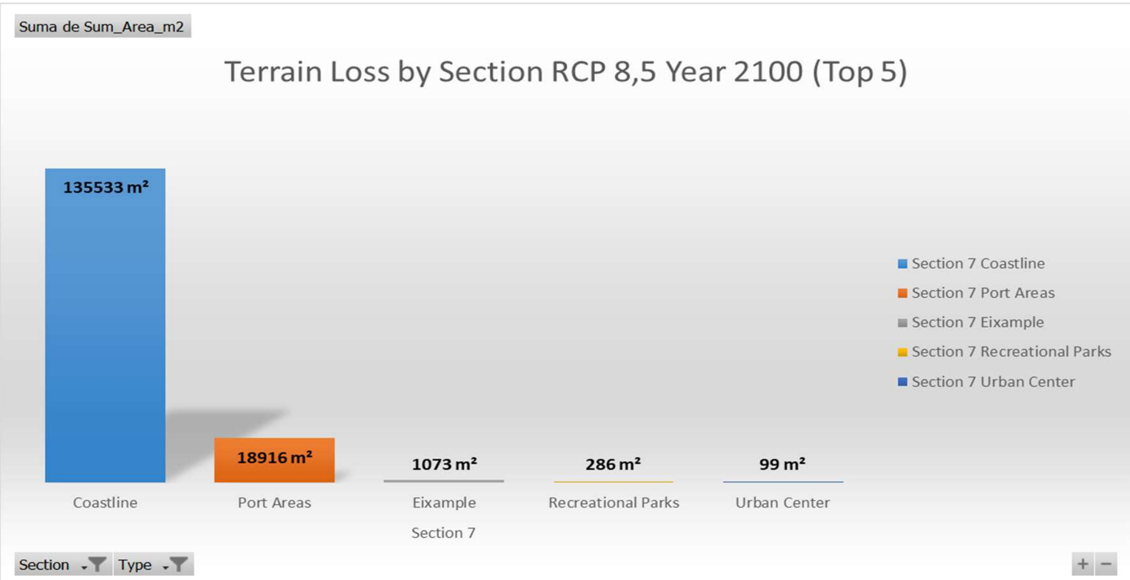

*Graphic 12. Section 6 (2100, RCP 8,5).*

### 3.1.7 Littoral Cell 7. Cubelles – Garraf.

*Illustration 43. Section 7 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 7 | Natural Uses* | 0,14 Km² | 135533 m² |
| | Port Areas | 0,02 Km² | 18916 m² |
| | Eixample | 0,00 Km² | 1073 m² |
| | Recreational Parks | 0,00 Km² | 286 m² |
| | Urban Center | 0,00 Km² | 99 m² |
| | Railways | 0,00 Km² | 69 m² |
| | Railways Green Areas | 0,00 Km² | 53 m² |
| | Golf Pitchs | 0,00 Km² | 50 m² |
| | Commercial Centers | 0,00 Km² | 36 m² |
| | Hotels | 0,00 Km² | 29 m² |

*Table 8. Section 7 Loss (2100, RCP 8,5).*




*Graphic 13. Section 7 (2100, RCP 8,5).*

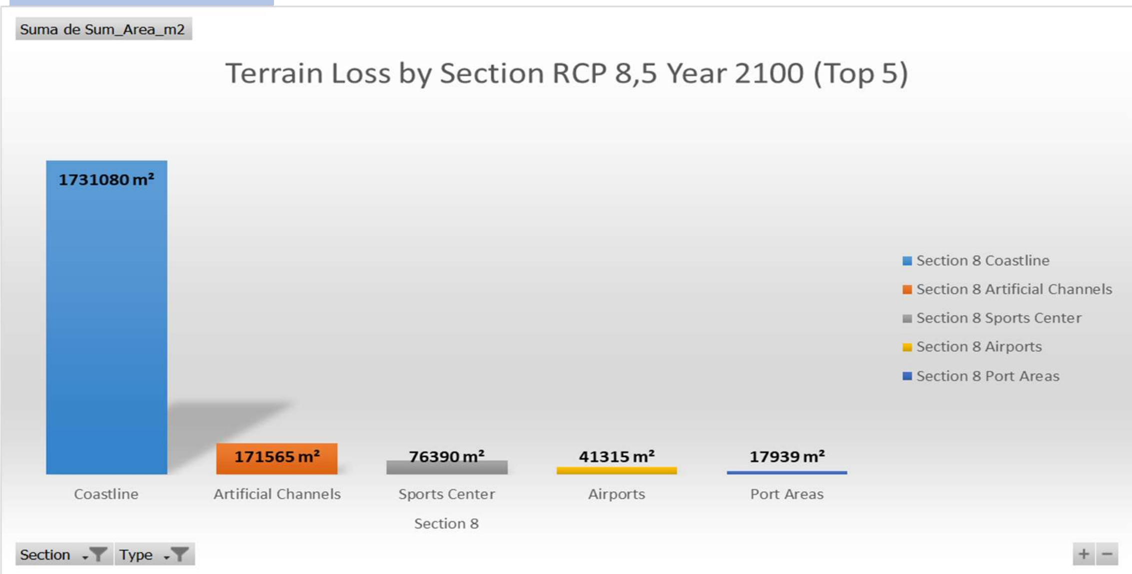
### 3.1.8 Littoral Cell 8. Port Ginesta – Port Barcelona.

*Illustration 44. Section 8 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 8 | Natural Uses* | 1,73 Km² | 1731080 m² |
| | Artificial Channels | 0,17 Km² | 171565 m² |
| | Sports Center | 0,08 Km² | 76390 m² |
| | Airports | 0,04 Km² | 41315 m² |
| | Port Areas | 0,02 Km² | 17939 m² |
| | Commercial Centers | 0,01 Km² | 11520 m² |
| | Urban Parks | 0,01 Km² | 8784 m² |
| | Roads | 0,01 Km² | 6679 m² |
| | Eixample | 0,01 Km² | 5095 m² |
| | Industrial Areas | 0,00 Km² | 4762 m² |
| | Family Garden | 0,00 Km² | 4160 m² |
| | Railways | 0,00 Km² | 3903 m² |
| | Desalination Plants | 0,00 Km² | 3284 m² |
| | Wastewater Treatment Plants | 0,00 Km² | 1838 m² |
| | Recreational Parks | 0,00 Km² | 1687 m² |
| | Motorways | 0,00 Km² | 785 m² |
| | Industrial Areas | 0,00 Km² | 537 m² |
| | Farms | 0,00 Km² | 329 m² |
| | Green Areas | 0,00 Km² | 323 m² |
| | Telecomunications | 0,00 Km² | 304 m² |
| | Hotels | 0,00 Km² | 293 m² |
| | Isolated Houses | 0,00 Km² | 240 m² |
| | Agricultural Use | 0,00 Km² | 151 m² |
| | Hibernacles | 0,00 Km² | 101 m² |
| | Treatment Plants | 0,00 Km² | 82 m² |

| | | | |
|---|---|---|---|
| | Golf Pitchs | 0,00 Km² | 71 m² |
| | Service Areas | 0,00 Km² | 65 m² |
| | Administrative Centers | 0,00 Km² | 56 m² |
| | Education Centers | 0,00 Km² | 28 m² |
| | Landfills | 0,00 Km² | 21 m² |
| | Campings | 0,00 Km² | 5 m² |

*Table 9. Section 8 Loss (2100, RCP 8,5).*



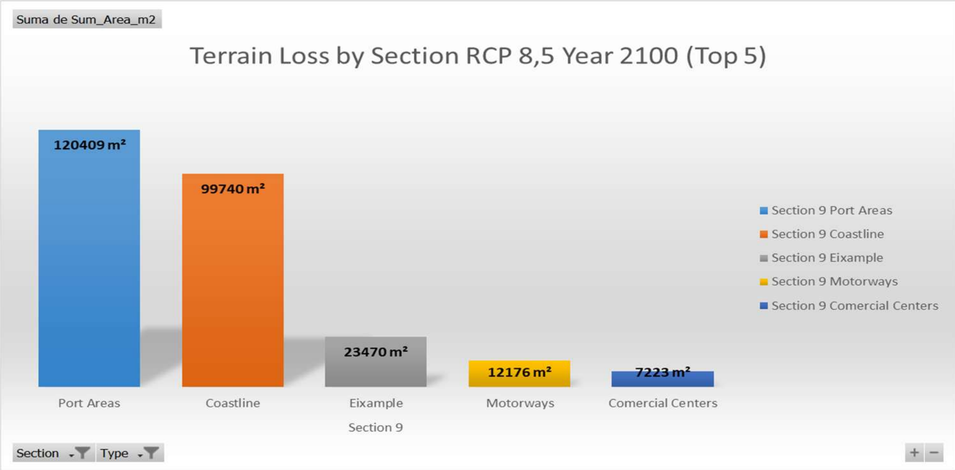

*Graphic 14. Section 8 (2100, RCP 8,5).*

### 3.1.9 Littoral Cell 9. Barcelona City.

*Illustration 45. Section 9 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 9 | Port Areas | 0,12 Km² | 120409 m² |
| | Natural Uses* | 0,10 Km² | 99740 m² |
| | Eixample | 0,02 Km² | 23470 m² |
| | Motorways | 0,01 Km² | 12176 m² |
| | Commercial Centers | 0,01 Km² | 7223 m² |
| | Industrial Areas | 0,01 Km² | 6662 m² |
| | Hotels | 0,00 Km² | 4984 m² |
| | Industrial Areas | 0,00 Km² | 4761 m² |
| | Green Areas | 0,00 Km² | 3543 m² |
| | Urban Parks | 0,00 Km² | 3248 m² |
| | Railways | 0,00 Km² | 1762 m² |
| | Electrical Infraestructures | 0,00 Km² | 1420 m² |
| | Urban Center | 0,00 Km² | 924 m² |
| | Cultural Centers | 0,00 Km² | 524 m² |
| | Sports Center | 0,00 Km² | 173 m² |
| | Administrative Centers | 0,00 Km² | 116 m² |
| | Recreational Parks | 0,00 Km² | 82 m² |
| | Education Centers | 0,00 Km² | 7 m² |
| | Railways Green Areas | 0,00 Km² | 2 m² |

*Table 10. Section 9 Loss (2100, RCP 8,5).*



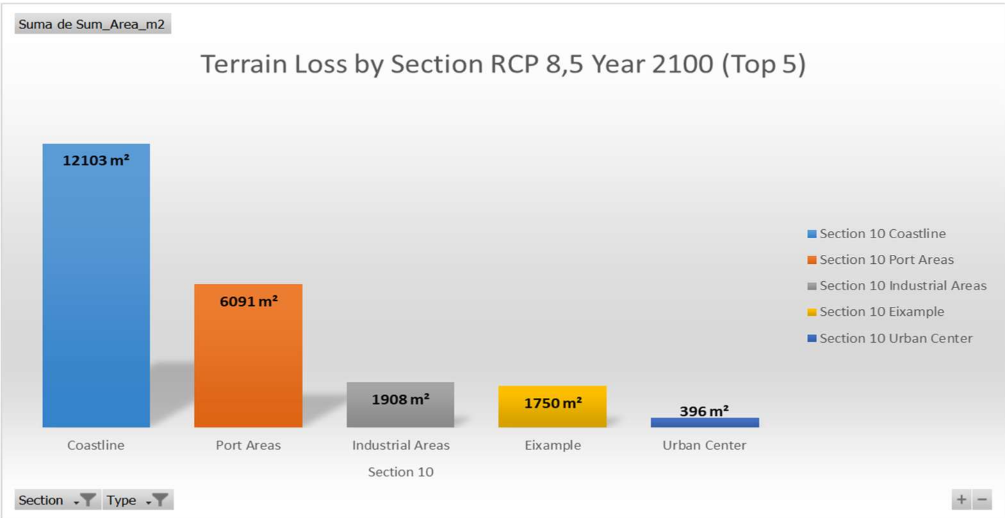

*Graphic 15. Section 9 (2100, RCP 8,5).*

### 3.1.10 Littoral Cell 10. Port de Badalona – Port Masnou.

*Illustration 46. Section 10 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 10 | Natural Uses* | 0,01 Km² | 12103 m² |
| | Port Areas | 0,01 Km² | 6091 m² |
| | Industrial Areas | 0,00 Km² | 1908 m² |
| | Eixample | 0,00 Km² | 1750 m² |
| | Urban Center | 0,00 Km² | 396 m² |
| | Roads | 0,00 Km² | 116 m² |
| | Urban Parks | 0,00 Km² | 84 m² |
| | Railways | 0,00 Km² | 60 m² |
| | Sports Center | 0,00 Km² | 28 m² |

*Table 11. Section 10 Loss (2100, RCP 8,5).*



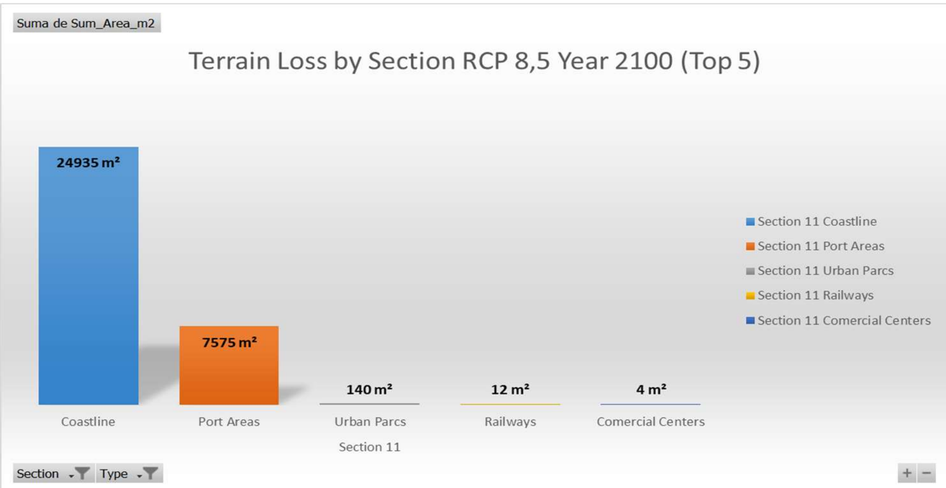

*Graphic 16. Section 10 (2100, RCP 8,5).*

### 3.1.11 Littoral Cell 11. Port Masnou – Port Premià.

*Illustration 47. Section 11 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 11 | Natural Uses* | 0,02 Km² | 24935 m² |
| | Port Areas | 0,01 Km² | 7575 m² |
| | Urban Parks | 0,00 Km² | 140 m² |
| | Railways | 0,00 Km² | 12 m² |
| | Commercial Centers | 0,00 Km² | 4 m² |

*Table 12. Section 11 Loss (2100, RCP 8,5).*



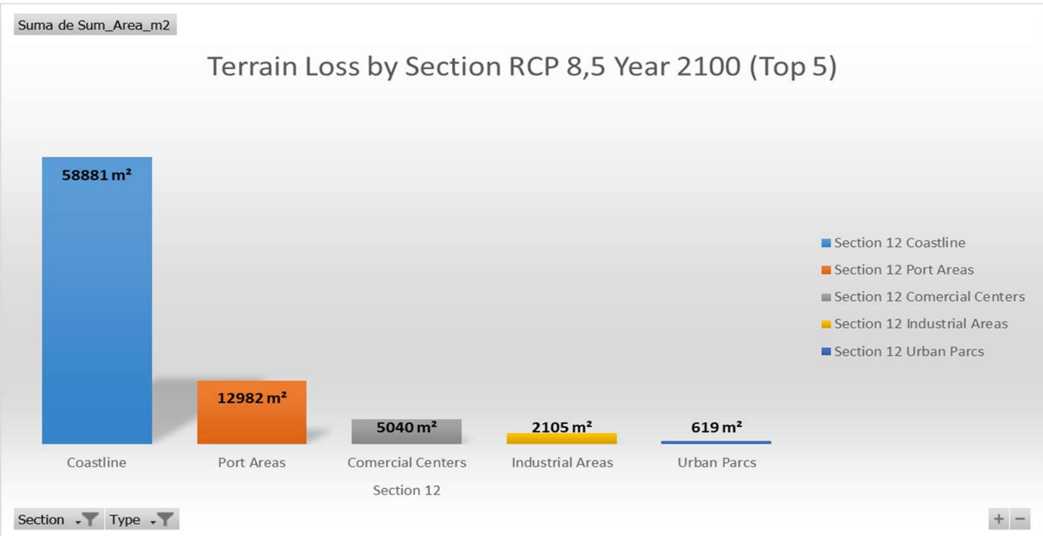

*Graphic 17. Section 11 (2100, RCP 8,5).*

### 3.1.12 Littoral Cell 12. Port Premià – Port Mataró.

*Illustration 48. Section 12 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 12 | Natural Uses* | 0,06 Km² | 58881 m² |
| | Port Areas | 0,01 Km² | 12982 m² |
| | Commercial Centers | 0,01 Km² | 5040 m² |
| | Industrial Areas | 0,00 Km² | 2105 m² |
| | Urban Parks | 0,00 Km² | 619 m² |
| | Hotels | 0,00 Km² | 356 m² |
| | Eixample | 0,00 Km² | 116 m² |
| | Railways | 0,00 Km² | 33 m² |
| | Isolated Houses | 0,00 Km² | 4 m² |

*Table 13. Section 12 Loss (2100, RCP 8,5).*




*Graphic 18. Section 12 (2100, RCP 8,5).*

### 3.1.13 Littoral Cell 13. Port Mataró – Port Balls.

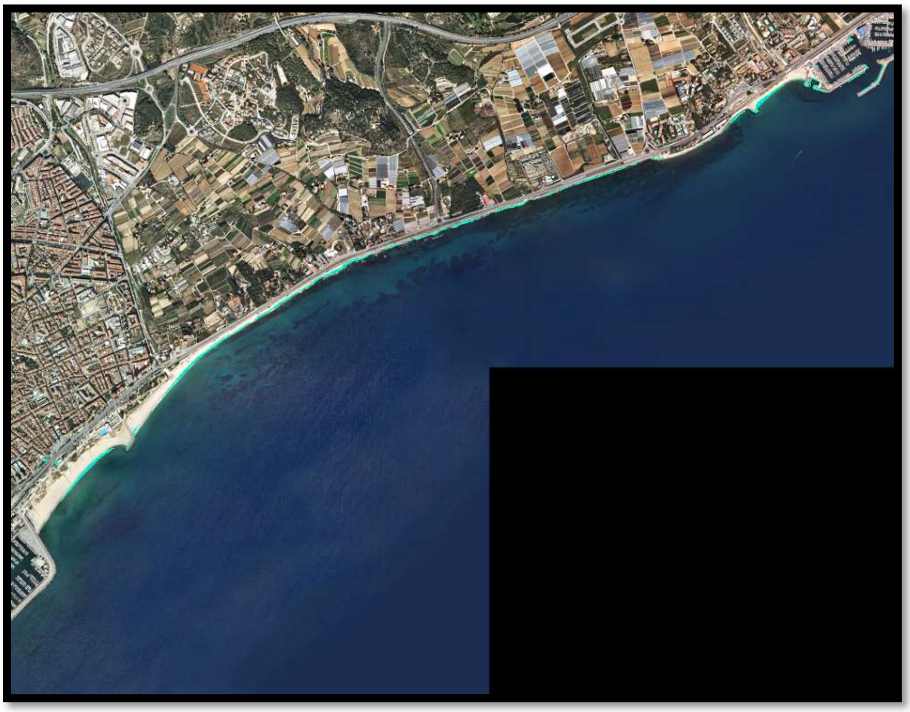
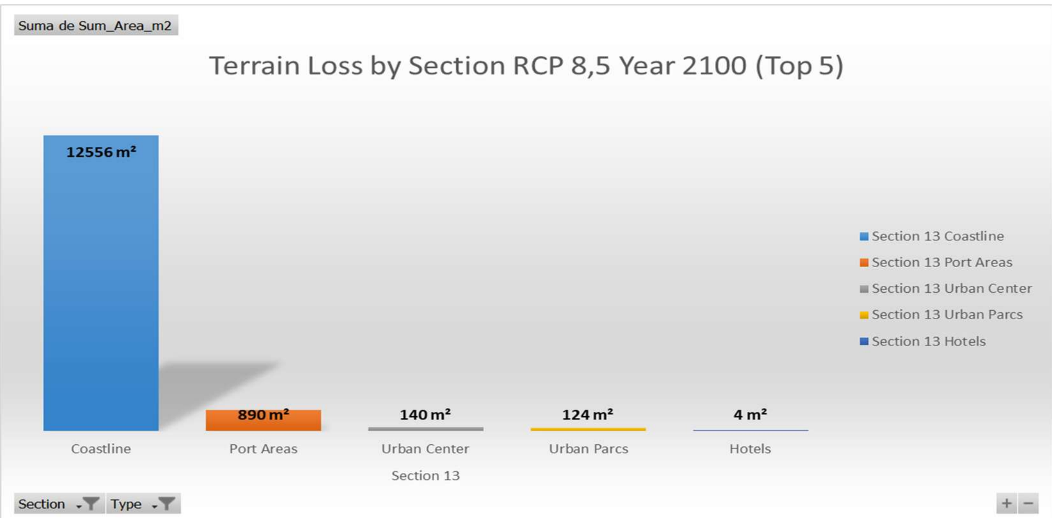


*Illustration 49. Section 13 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 13 | Natural Uses* | 0,01 Km² | 12556 m² |
| | Port Areas | 0,00 Km² | 890 m² |
| | Urban Center | 0,00 Km² | 140 m² |
| | Urban Parks | 0,00 Km² | 124 m² |
| | Hotels | 0,00 Km² | 4 m² |

*Table 14. Section 13 Loss (2100, RCP 8,5).*




*Graphic 19. Section 13 (2100, RCP 8,5).*

### 3.1.14 Littoral Cell 14. Port Balls – Port Arenys.

*Illustration 50. Section 14 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 14 | Natural Uses* | 0,03 Km² | 31036 m² |
| | Port Areas | 0,01 Km² | 5042 m² |
| | Urban Center | 0,00 Km² | 13 m² |

*Table 15. Section 14 Loss (2100, RCP 8,5).*

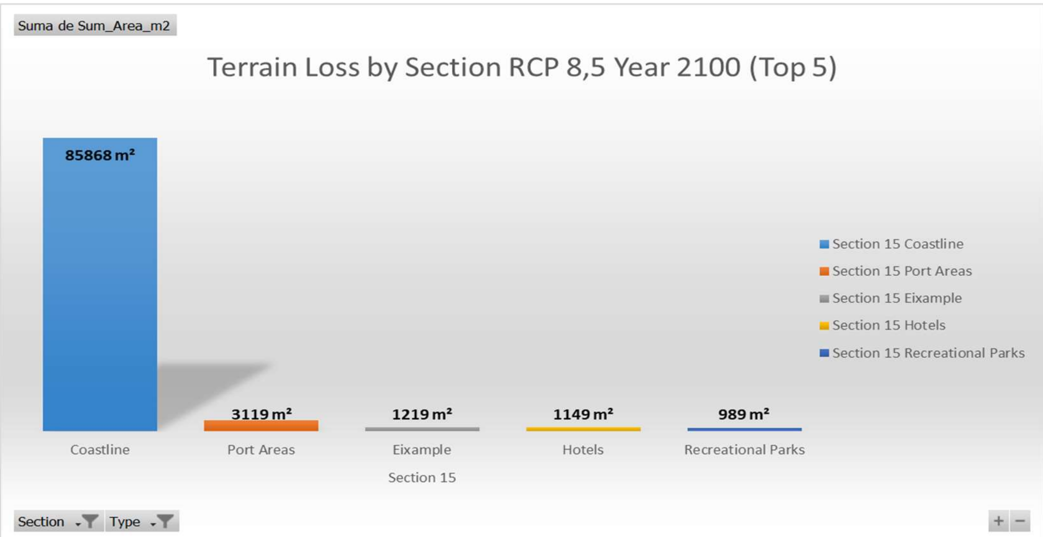

*Graphic 20. Section 14 (2100, RCP 8,5).*

### 3.1.15 Littoral Cell 15. Port Arenys – Port Blanes.

*Illustration 51. Section 16 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 15 | Natural Uses* | 0,09 Km² | 85868 m² |
| | Campings | 0,00 Km² | 79 m² |
| | Eixample | 0,00 Km² | 1219 m² |
| | Hotels | 0,00 Km² | 1149 m² |
| | Industrial Areas | 0,00 Km² | 492 m² |
| | Isolated Houses | 0,00 Km² | 120 m² |
| | Port Areas | 0,00 Km² | 3119 m² |
| | Railways | 0,00 Km² | 371 m² |
| | Recreational Parks | 0,00 Km² | 989 m² |
| | Urban Center | 0,00 Km² | 71 m² |
| | Urban Parks | 0,00 Km² | 47 m² |

*Table 16. Section 15 Loss (2100, RCP 8,5).*



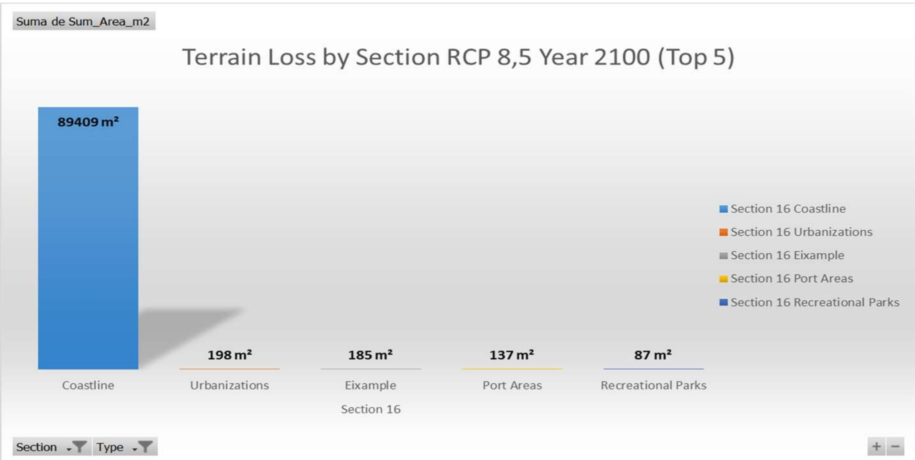

*Graphic 21. Section 15 (2100, RCP 8,5).*

### 3.1.16 Littoral Cell 16. Port Blanes – Llosa des Llevador.

*Illustration 52. Section 16 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 16 | Natural Uses* | 0,09 Km² | 89409 m² |
| | Urbanizations | 0,00 Km² | 198 m² |
| | Eixample | 0,00 Km² | 185 m² |
| | Port Areas | 0,00 Km² | 137 m² |
| | Recreational Parks | 0,00 Km² | 87 m² |

*Table 17. Section 16 Loss (2100, RCP 8,5).*




*Graphic 22. Section 16 (2100, RCP 8,5).*

### 3.1.17 Littoral Cell 17. Llosa des Llevador – Marina de Palamós.

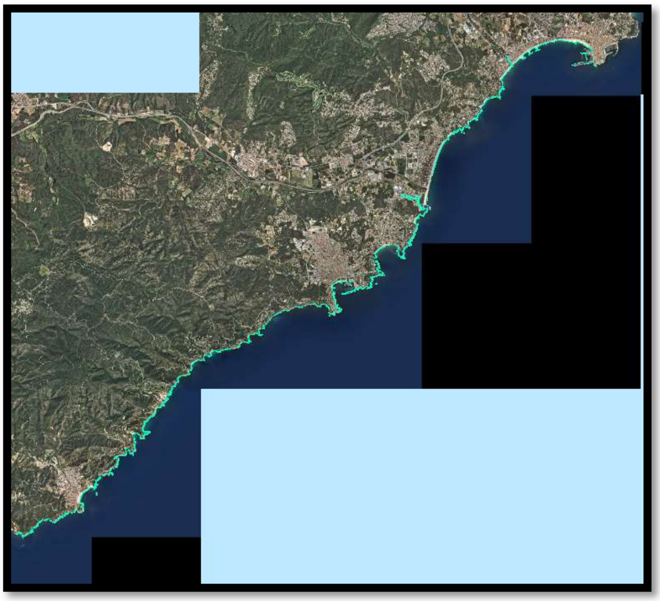
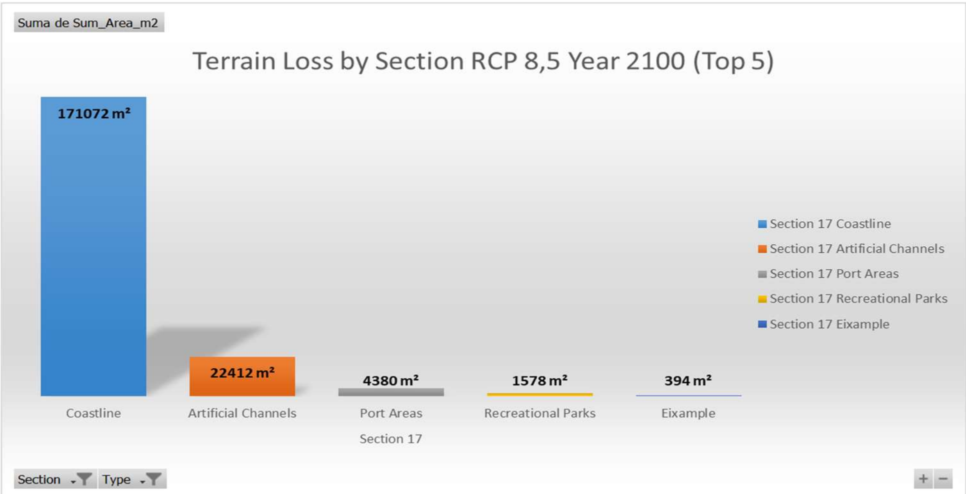


*Illustration 53. Section 17 (2100, RCP 8,5).*

| Section | Type | Area ($Km^2$) | Area ($m^2$) |
|---|---|---|---|
| Section 17 | Natural Uses* | 0,17 $Km^2$ | 171072 $m^2$ |
| | Artificial Channels | 0,02 $Km^2$ | 22412 $m^2$ |
| | Port Areas | 0,00 $Km^2$ | 4380 $m^2$ |
| | Recreational Parks | 0,00 $Km^2$ | 1578 $m^2$ |
| | Eixample | 0,00 $Km^2$ | 394 $m^2$ |
| | Urban Center | 0,00 $Km^2$ | 169 $m^2$ |
| | Urban Parks | 0,00 $Km^2$ | 110 $m^2$ |
| | Urbanizations | 0,00 $Km^2$ | 55 $m^2$ |
| | Industrial Areas | 0,00 $Km^2$ | 36 $m^2$ |

*Table 18. Section 17 Loss (2100, RCP 8,5).*




*Graphic 23. Section 17 (2100, RCP 8,5).*

### 3.1.18 Littoral Cell 18. Marina de Palamós – Platja de Tamariu.

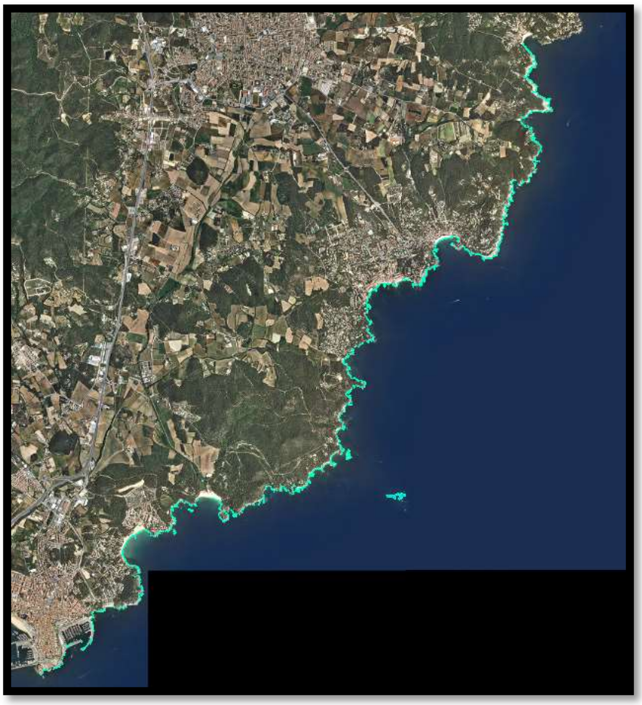
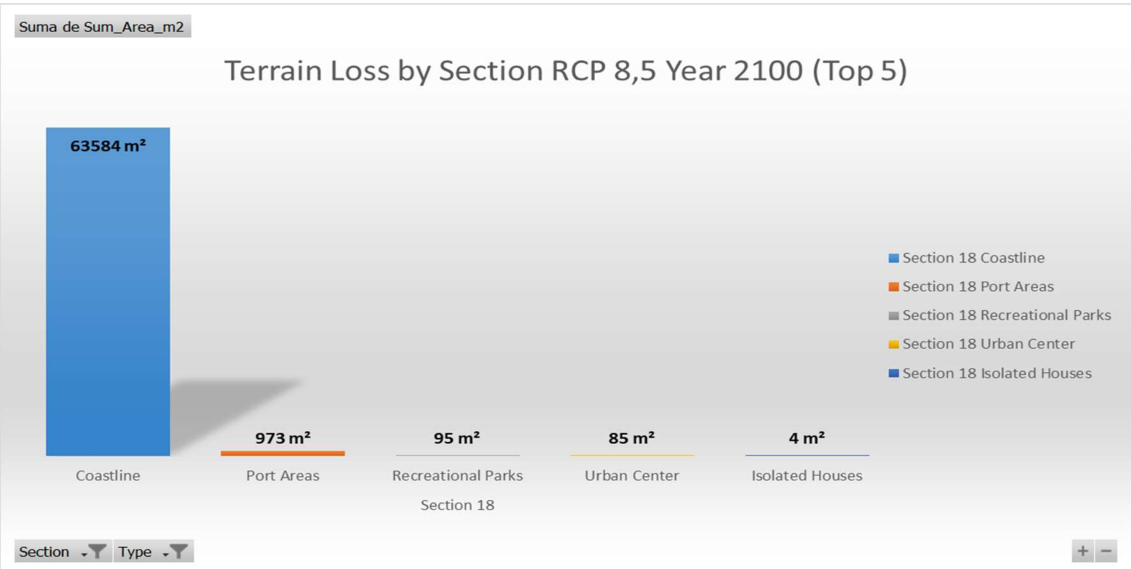


*Illustration 54. Section 18 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 18 | Natural Uses* | 0,06 Km² | 63584 m² |
| | Port Areas | 0,00 Km² | 973 m² |
| | Recreational Parks | 0,00 Km² | 95 m² |
| | Urban Center | 0,00 Km² | 85 m² |
| | Isolated Houses | 0,00 Km² | 4 m² |

*Table 19. Section 18 Loss (2100, RCP 8,5).*




*Graphic 24. Section 18 (2100, RCP 8,5).*

### 3.1.19 Littoral Cell 19. Platja de Tamariu – Port Escala.

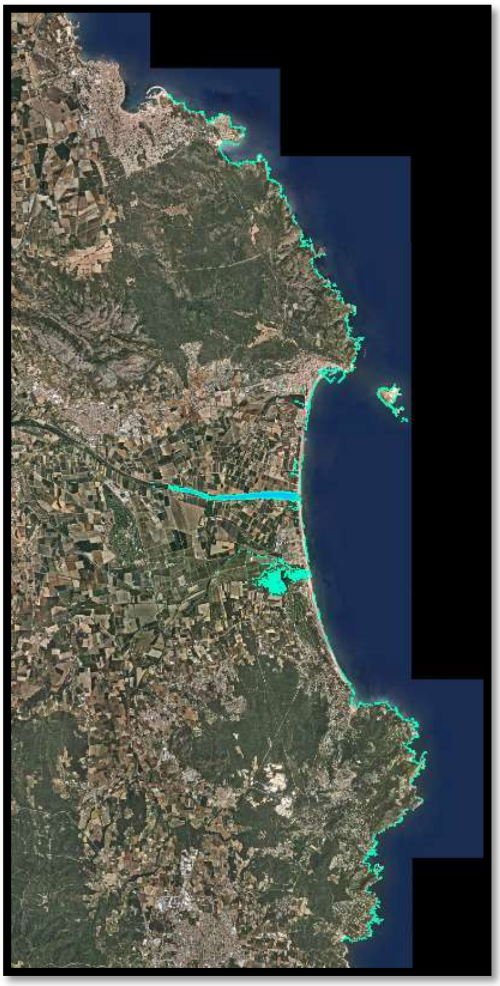
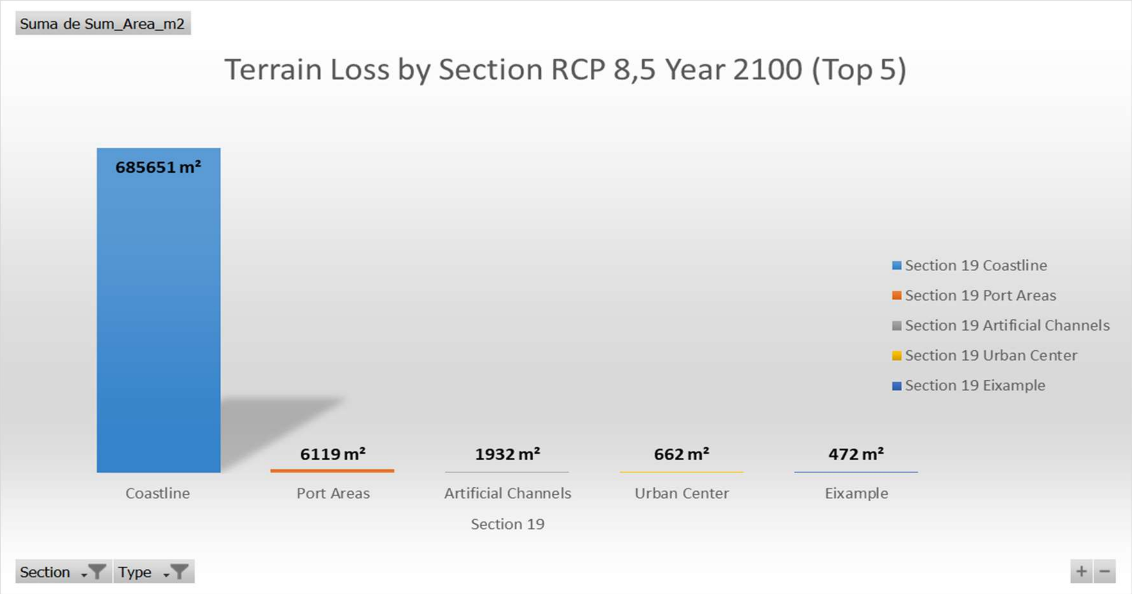


*Illustration 55. Section 19 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 19 | Natural Uses* | 0,69 Km² | 685651 m² |
| | Artificial Channels | 0,00 Km² | 1932 m² |
| | Campings | 0,00 Km² | 64 m² |
| | Eixample | 0,00 Km² | 472 m² |
| | Hotels | 0,00 Km² | 48 m² |
| | Isolated Houses | 0,00 Km² | 210 m² |
| | Port Areas | 0,01 Km² | 6119 m² |
| | Recreational Parks | 0,00 Km² | 60 m² |
| | Urban Center | 0,00 Km² | 662 m² |
| | Urbanizations | 0,00 Km² | 55 m² |

*Table 20. Section 19 Loss (2100, RCP 8,5).*



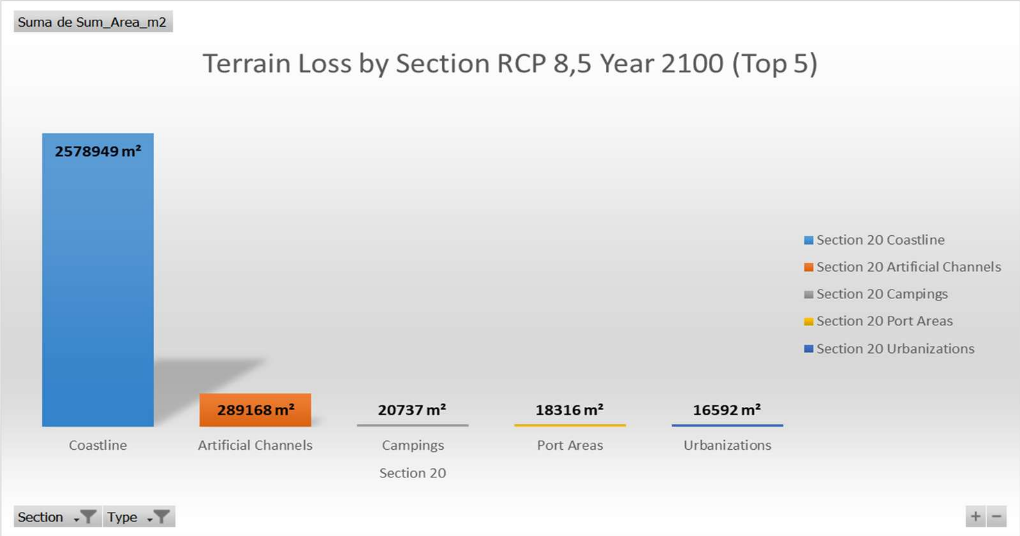

*Graphic 25. Section 19 (2100, RCP 8,5).*

### 3.1.20 Littoral Cell 20. Port Escala – Port Roses.

*Illustration 56. Section 20 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 20 | Natural Uses* | 2,58 Km² | 2578949 m² |
| | Artificial Channels | 0,29 Km² | 289168 m² |
| | Campings | 0,02 Km² | 20737 m² |
| | Port Areas | 0,02 Km² | 18316 m² |
| | Urbanizations | 0,02 Km² | 16592 m² |
| | Eixample | 0,00 Km² | 4801 m² |
| | Recreational Parks | 0,00 Km² | 3978 m² |
| | Roads | 0,00 Km² | 1055 m² |
| | Green Areas | 0,00 Km² | 747 m² |
| | Urban Parks | 0,00 Km² | 559 m² |
| | Hotels | 0,00 Km² | 527 m² |
| | Motorways | 0,00 Km² | 472 m² |
| | Commercial Centers | 0,00 Km² | 339 m² |
| | Isolated Houses | 0,00 Km² | 150 m² |
| | Urban Center | 0,00 Km² | 93 m² |
| | Agricultural Use | 0,00 Km² | 92 m² |
| | Farms | 0,00 Km² | 49 m² |
| | Hibernacles | 0,00 Km² | 20 m² |
| | Industrial Areas | 0,00 Km² | 15 m² |
| | Sports Center | 0,00 Km² | 2 m² |

*Table 21. Section 20 Loss (2100, RCP 8,5).*



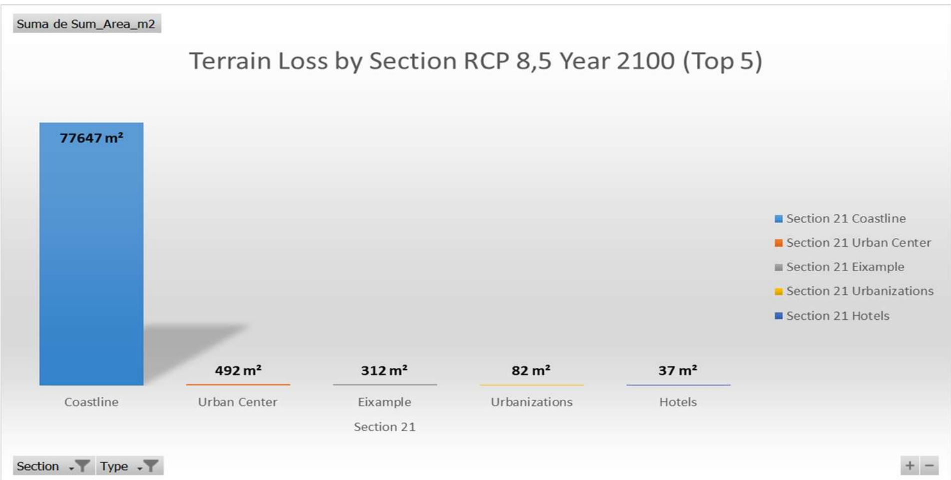

*Graphic 26. Section 20 (2100, RCP 8,5).*

### 3.1.21 Littoral Cell 21. Port Roses – Platja Portlligat.

*Illustration 57. Section 21 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 21 | Natural Uses* | 0,08 Km² | 77647 m² |
| | Urban Center | 0,00 Km² | 492 m² |
| | Eixample | 0,00 Km² | 312 m² |
| | Urbanizations | 0,00 Km² | 82 m² |
| | Hotels | 0,00 Km² | 37 m² |
| | Commercial Centers | 0,00 Km² | 22 m² |
| | Recreational Parks | 0,00 Km² | 11 m² |
| | Cultural Centers | 0,00 Km² | 1 m² |

*Table 22. Section 21 Loss (2100, RCP 8,5).*




*Graphic 27. Section 21 (2100, RCP 8,5).*

### 3.1.22 Littoral Cell 22. Punta Noves – Platja Portbou.

*Illustration 58. Section 22 (2100, RCP 8,5).*

| Section | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Section 22 | Natural Uses* | 0,24 Km² | 236551 m² |
| | Port Areas | 0,00 Km² | 3417 m² |
| | Urban Center | 0,00 Km² | 587 m² |
| | Recreational Parks | 0,00 Km² | 192 m² |
| | Campings | 0,00 Km² | 160 m² |
| | Eixample | 0,00 Km² | 91 m² |
| | Family Garden | 0,00 Km² | 35 m² |
| | Roads | 0,00 Km² | 8 m² |
| | Commercial Centers | 0,00 Km² | 4 m² |
| | Hotels | 0,00 Km² | 3 m² |

*Table 23. Section 22 Loss (2100, RCP 8,5).*


*Graphic 28. Section 22 (2100, RCP 8,5).*

## 3.2 Vulnerabilities

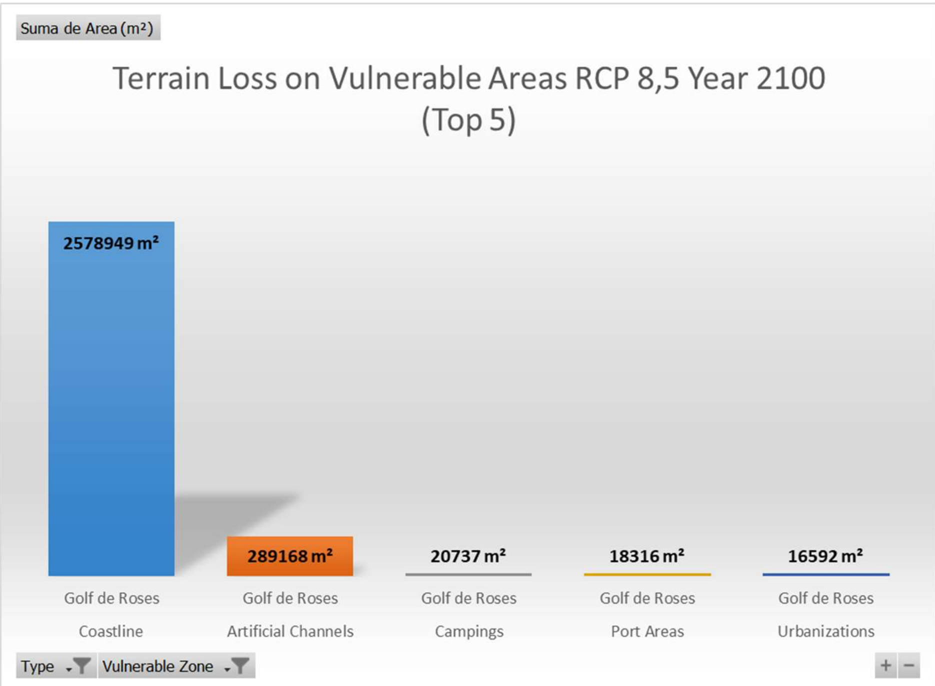
In this part, we are going to take a closer look to the identified areas worth of a more detailed approach.

### 3.2.1 Roses Gulf

*Illustration 59. Roses Gulf Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Roses Gulf | Natural Uses* | 2,58 Km² | 2578949 m² |
| | Artificial Channels | 0,29 Km² | 289168 m² |
| | Campings | 0,02 Km² | 20737 m² |
| | Port Areas | 0,02 Km² | 18316 m² |
| | Urbanizations | 0,02 Km² | 16592 m² |
| | Eixample | 0,00 Km² | 4801 m² |
| | Recreational Parks | 0,00 Km² | 3978 m² |
| | Roads | 0,00 Km² | 1055 m² |
| | Green Areas | 0,00 Km² | 747 m² |
| | Urban Parks | 0,00 Km² | 559 m² |
| | Hotels | 0,00 Km² | 527 m² |
| | Motorways | 0,00 Km² | 472 m² |
| | Commercial Centers | 0,00 Km² | 339 m² |
| | Isolated Houses | 0,00 Km² | 150 m² |
| | Urban Center | 0,00 Km² | 93 m² |
| | Agricultural Use | 0,00 Km² | 92 m² |
| | Farms | 0,00 Km² | 49 m² |
| | Hibernacles | 0,00 Km² | 20 m² |
| | Industrial Areas | 0,00 Km² | 15 m² |
| | Sports Center | 0,00 Km² | 2 m² |
| | Family Garden | 0,00 Km² | 0 m² |

*Table 24. Roses Gulf Land Loss (2100, RCP 8,5).*




*Graphic 29. Roses Gulf Land Loss (2100, RCP 8,5).*

### 3.2.2 L'Estartit

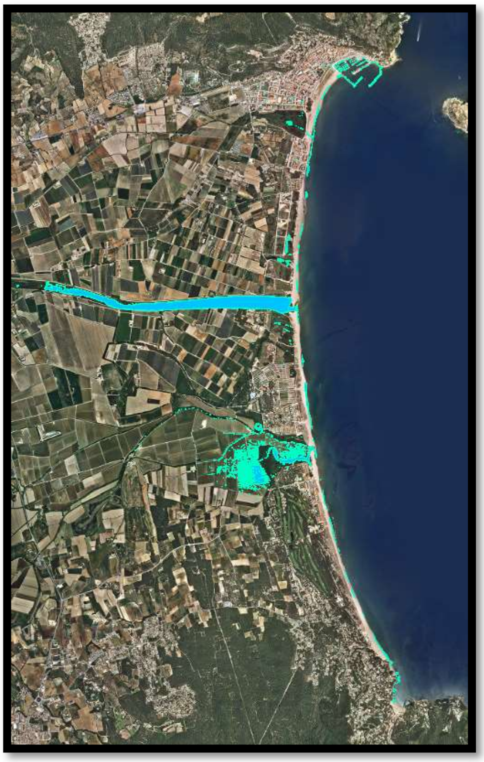
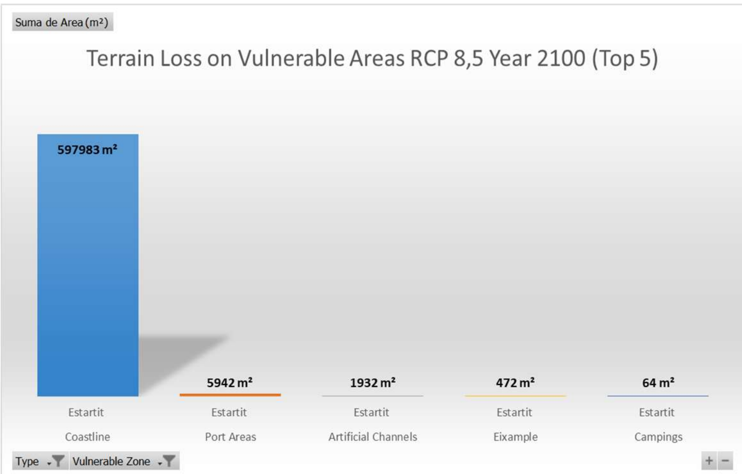


*Illustration 60. L'Estartit Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| Estartit | Delta & Wetlands | 0,60 Km² | 597983 m² |
| | Port Areas | 0,01 Km² | 5942 m² |
| | Artificial Channels | 0,00 Km² | 1932 m² |
| | Eixample | 0,00 Km² | 472 m² |
| | Campings | 0,00 Km² | 64 m² |
| | Hotels | 0,00 Km² | 48 m² |
| | Recreational Parks | 0,00 Km² | 14 m² |

*Table 25. L'Estartit Land Loss (2100, RCP 8,5).*




*Graphic 30. L'Estartit Land Loss (2100, RCP 8,5).*

### 3.2.3 La Tordera

*Illustration 61. La Tordera Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| La Tordera | Delta | 0,02 $Km^2$ | 19623 $m^2$ |

*Table 26. La Tordera Land Loss (2100, RCP 8,5).*

### 3.2.4 El Besòs

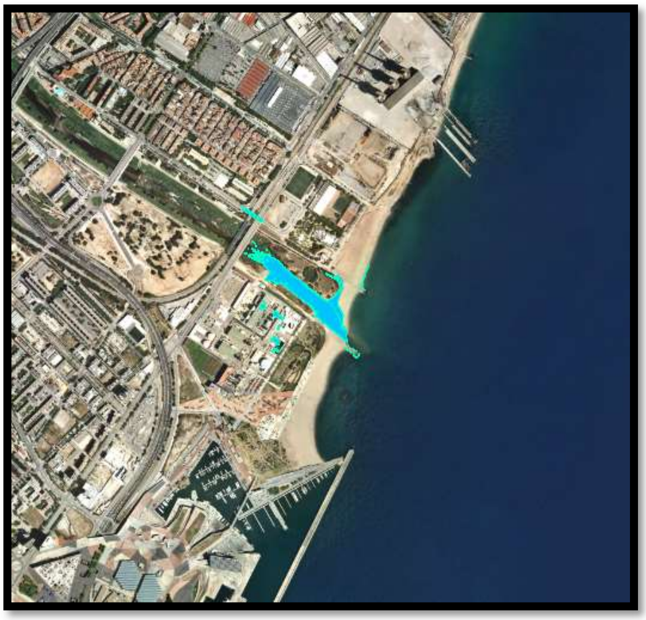
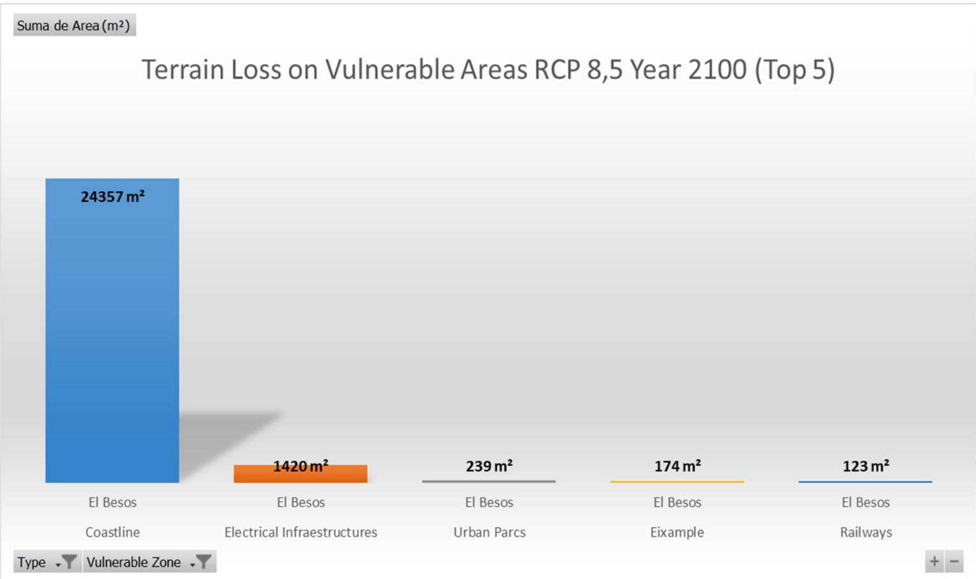


*Illustration 62. El Besòs Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| El Besos | Delta | 0,02 Km² | 24357 m² |
| | Electrical Infraestructures | 0,00 Km² | 1420 m² |
| | Urban Parks | 0,00 Km² | 239 m² |
| | Eixample | 0,00 Km² | 174 m² |
| | Railways | 0,00 Km² | 123 m² |

*Table 27. El Besòs Land Loss (2100, RCP 8,5).*



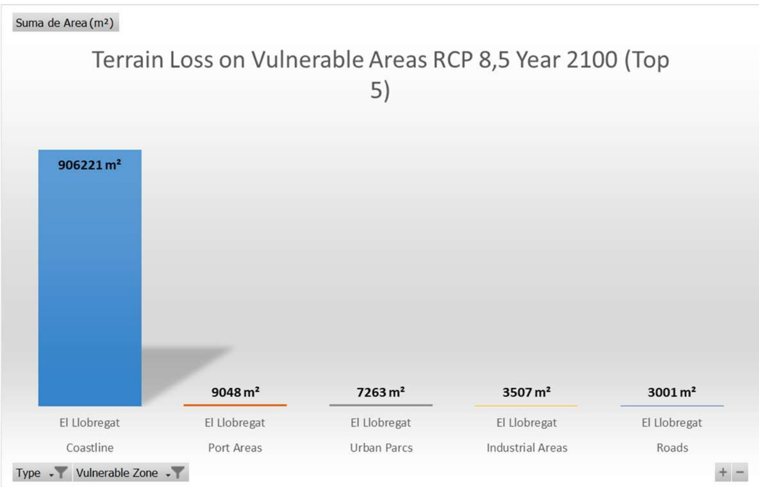

*Graphic 31. El Besòs Land Loss (2100, RCP 8,5).*

### 3.2.5 El Llobregat

*Illustration 63. El Llobregat Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| El Llobregat | Natural Uses* | 0,91 Km² | 906221 m² |
| | Port Areas | 0,01 Km² | 9048 m² |
| | Urban Parks | 0,01 Km² | 7263 m² |
| | Industrial Areas | 0,00 Km² | 3507 m² |
| | Roads | 0,00 Km² | 3001 m² |
| | Railways | 0,00 Km² | 2007 m² |
| | Desalination Plants | 0,00 Km² | 1388 m² |
| | Eixample | 0,00 Km² | 588 m² |
| | Industrial Areas | 0,00 Km² | 128 m² |
| | Service Areas | 0,00 Km² | 65 m² |

*Table 28. El Llobregat Land Loss (2100, RCP 8,5).*




*Graphic 32. El Llobregat Land Loss (2100, RCP 8,5).*

### 3.2.6 El Prat

*Illustration 64. El Prat Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| El Prat | Natural Uses* | 0,81 Km² | 808137 m² |
| | Artificial Channels | 0,17 Km² | 171565 m² |
| | Sports Center | 0,08 Km² | 76390 m² |
| | Airports | 0,04 Km² | 41315 m² |
| | Commercial Centers | 0,01 Km² | 11520 m² |
| | Family Garden | 0,00 Km² | 4160 m² |
| | Eixample | 0,00 Km² | 4063 m² |
| | Roads | 0,00 Km² | 3678 m² |
| | Railways | 0,00 Km² | 1896 m² |
| | Wastewater Treatment Plants | 0,00 Km² | 1838 m² |
| | Recreational Parks | 0,00 Km² | 1659 m² |
| | Urban Parks | 0,00 Km² | 1521 m² |
| | Port Areas | 0,00 Km² | 1318 m² |
| | Industrial Areas | 0,00 Km² | 1255 m² |
| | Motorways | 0,00 Km² | 785 m² |
| | Industrial Areas | 0,00 Km² | 409 m² |
| | Farms | 0,00 Km² | 329 m² |
| | Telecomunications | 0,00 Km² | 304 m² |
| | Hotels | 0,00 Km² | 292 m² |
| | Green Areas | 0,00 Km² | 289 m² |
| | Isolated Houses | 0,00 Km² | 240 m² |
| | Agricultural Use | 0,00 Km² | 151 m² |
| | Hibernacles | 0,00 Km² | 101 m² |
| | Treatment Plants | 0,00 Km² | 82 m² |
| | Golf Pitchs | 0,00 Km² | 71 m² |
| | Administrative Centers | 0,00 Km² | 56 m² |
| | Education Centers | 0,00 Km² | 28 m² |
| | Landfills | 0,00 Km² | 21 m² |
| | Campings | 0,00 Km² | 5 m² |

*Table 29. El Prat Land Loss (2100, RCP 8,5).*


*Graphic 33. El Pratt Land Loss (2100, RCP 8,5).*

### 3.2.7 El Foix

*Illustration 65. El Foix Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area (Km²) | Area (m²) |
|---|---|---|---|
| El Foix | Delta | 0,01 Km² | 12150 m² |

*Table 30. El Foix Land Loss (2100, RCP 8,5).*

### 3.2.8 Ebre Delta

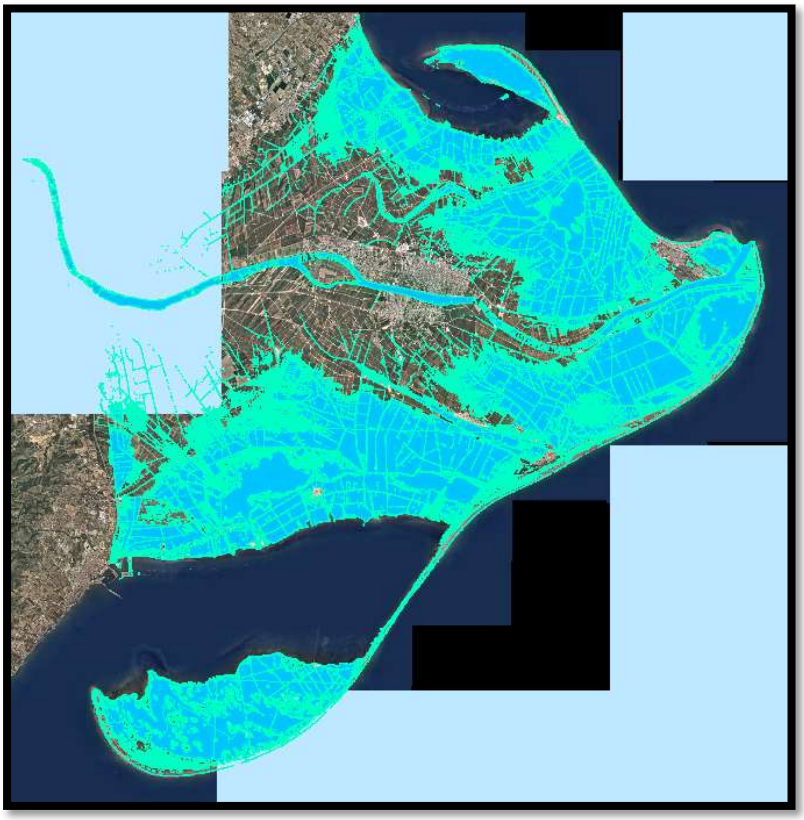
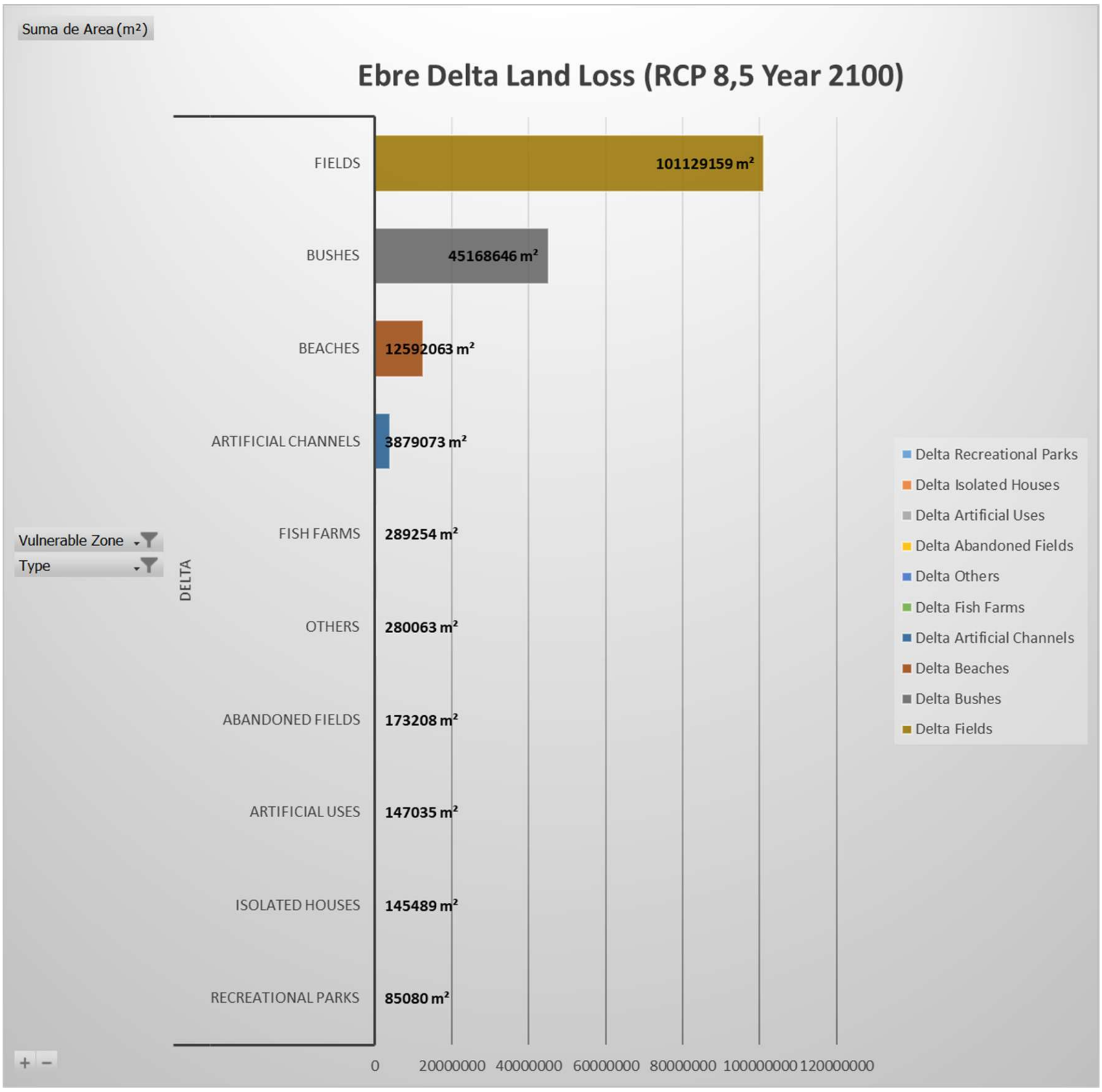


*Illustration 66. Ebre Delta Land Loss (2100, RCP 8,5).*

| Vulnerable Zone | Type | Area ($Km^2$) | Area ($m^2$) |
|---|---|---|---|
| Ebre Delta | Fields | 101,13 $Km^2$ | 101129159 $m^2$ |
| | Bushes | 45,17 $Km^2$ | 45168646 $m^2$ |
| | Beaches | 12,59 $Km^2$ | 12592063 $m^2$ |
| | Artificial Channels | 3,88 $Km^2$ | 3879073 $m^2$ |
| | Fish Farms | 0,29 $Km^2$ | 289254 $m^2$ |
| | Others | 0,28 $Km^2$ | 280063 $m^2$ |
| | Abandoned Fields | 0,17 $Km^2$ | 173208 $m^2$ |
| | Artificial Uses | 0,15 $Km^2$ | 147035 $m^2$ |
| | Isolated Houses | 0,15 $Km^2$ | 145489 $m^2$ |
| | Recreational Parks | 0,09 $Km^2$ | 85080 $m^2$ |
| | Wetlands | 0,05 $Km^2$ | 51709 $m^2$ |
| | Farms | 0,05 $Km^2$ | 46516 $m^2$ |
| | Agricultural Use | 0,03 $Km^2$ | 32964 $m^2$ |
| | Roads | 0,03 $Km^2$ | 29355 $m^2$ |
| | Port Areas | 0,02 $Km^2$ | 17235 $m^2$ |
| | Family Garden | 0,02 $Km^2$ | 16374 $m^2$ |
| | Urban Parcs | 0,01 $Km^2$ | 11837 $m^2$ |
| | Urbanizations | 0,01 $Km^2$ | 11205 $m^2$ |
| | Sports Center | 0,01 $Km^2$ | 11094 $m^2$ |
| | Green Areas | 0,01 $Km^2$ | 8993 $m^2$ |
| | Industrail Areas | 0,01 $Km^2$ | 8459 $m^2$ |
| | Motorways | 0,01 $Km^2$ | 6421 $m^2$ |
| | Campings | 0,00 $Km^2$ | 2815 $m^2$ |
| | Mining Extraction Areas | 0,00 $Km^2$ | 2440 $m^2$ |
| | Cultural Centers | 0,00 $Km^2$ | 1324 $m^2$ |
| | Urban Center | 0,00 $Km^2$ | 1139 $m^2$ |
| | Railways | 0,00 $Km^2$ | 851 $m^2$ |
| | Comercial Centers | 0,00 $Km^2$ | 396 $m^2$ |
| | Eixample | 0,00 $Km^2$ | 380 $m^2$ |
| | Electrical Infraestructures | 0,00 $Km^2$ | 306 $m^2$ |
| | Cementeries | 0,00 $Km^2$ | 280 $m^2$ |
| | Administrative Centers | 0,00 $Km^2$ | 219 $m^2$ |
| | Hotels | 0,00 $Km^2$ | 191 $m^2$ |
| | Golf Pitchs | 0,00 $Km^2$ | 132 $m^2$ |
| | Wasterwater Treatment Plants | 0,00 $Km^2$ | 71 $m^2$ |
| | Hibernacles | 0,00 $Km^2$ | 17 $m^2$ |
| | Treatment Plants | 0,00 $Km^2$ | 12 $m^2$ |

*Table 31. Ebre Delta Land Loss (2100, RCP 8,5).*




*Graphic 34. Ebre Delta Land Loss (2100, RCP 8,5).*

### 3.3 Municipalities

The municipalities layer will be crossed with the land uses layer, using the intersect tool. The information that we will get will tell us which type of areas, and which amount of terrain are lost on any given coastal municipality.

The chart exposes those results, by alphabetical order of the distinct coastal municipalities (see the annex 5.1.5).

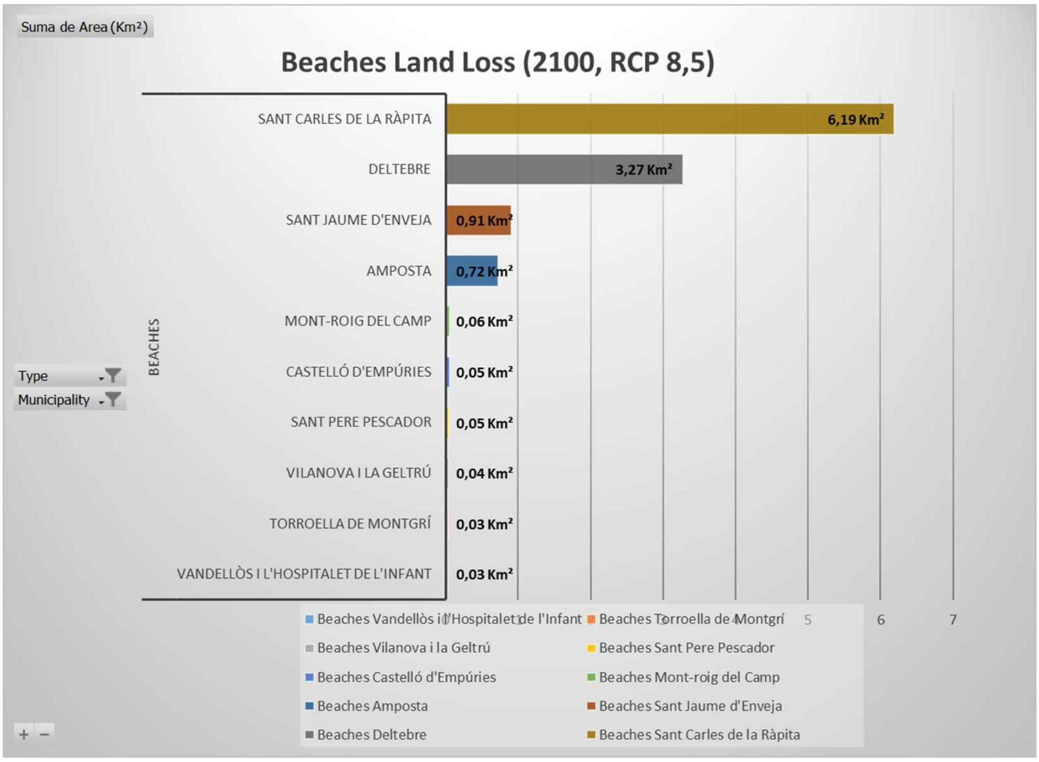
### 3.4 Land Uses

And finally, we will present the results according to the most relevant land uses, identifying which municipalities suffer the worst consequences. For more detailed results, see the annexes 5.1.3.

| | RCP 8,5, Year 2100 | |
|---|---|---|
| Type | Area (Km²) | Area (m²) |
| Fields | 101,70 Km² | 101698491 m² |
| Bushes & Forests | 47,07 Km² | 47070551 m² |
| Beaches | 11,88 Km² | 11880353 m² |
| Artificial Channels | 4,30 Km² | 4298777 m² |
| Others | 0,75 Km² | 754568 m² |
| Fish Farms | 0,27 Km² | 268917 m² |
| Abandoned Fields | 0,25 Km² | 252231 m² |
| Artificial Uses | 0,15 Km² | 150608 m² |
| Isolated Houses | 0,15 Km² | 145720 m² |
| Port Areas | 0,14 Km² | 135311 m² |
| Recreational Parks | 0,09 Km² | 93779 m² |
| Sports Center | 0,09 Km² | 87787 m² |
| Wetlands | 0,05 Km² | 51709 m² |
| Farms | 0,05 Km² | 46894 m² |
| Eixample | 0,04 Km² | 44680 m² |
| Roads | 0,04 Km² | 37216 m² |
| Agricultural Use | 0,03 Km² | 33206 m² |
| Urbanizations | 0,03 Km² | 30632 m² |
| Urban Parcs | 0,03 Km² | 26150 m² |
| Industrail Areas | 0,03 Km² | 26007 m² |
| Comercial Centers | 0,02 Km² | 24854 m² |
| Campings | 0,02 Km² | 24099 m² |
| Motorways | 0,02 Km² | 22992 m² |
| Family Garden | 0,02 Km² | 20568 m² |
| Green Areas | 0,01 Km² | 13775 m² |
| Railways | 0,01 Km² | 8283 m² |

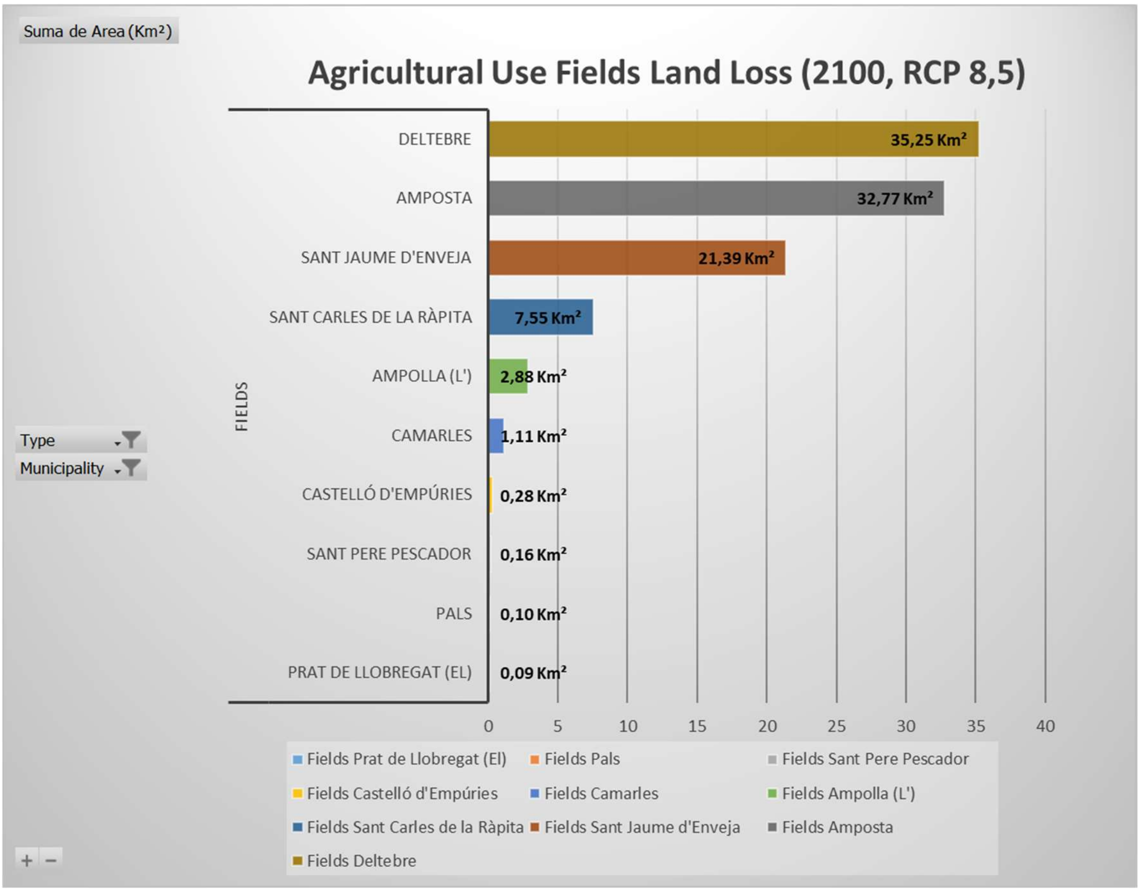
| | | |
|---|---|---|
| Hotels | 0,01 $Km^2$ | 7927 $m^2$ |
| Urban Center | 0,00 $Km^2$ | 4373 $m^2$ |
| Desalination Plants | 0,00 $Km^2$ | 3284 $m^2$ |
| Mining Extraction Areas | 0,00 $Km^2$ | 2440 $m^2$ |
| Wasterwater Treatment Plants | 0,00 $Km^2$ | 1924 $m^2$ |
| Electrical Infraestructures | 0,00 $Km^2$ | 1726 $m^2$ |
| Cultural Centers | 0,00 $Km^2$ | 1351 $m^2$ |
| Nuclear Plants | 0,00 $Km^2$ | 1167 $m^2$ |
| Health Centers | 0,00 $Km^2$ | 456 $m^2$ |
| Golf Pitchs | 0,00 $Km^2$ | 433 $m^2$ |
| Administrative Centers | 0,00 $Km^2$ | 391 $m^2$ |
| Education Centers | 0,00 $Km^2$ | 385 $m^2$ |
| Telecomunications | 0,00 $Km^2$ | 304 $m^2$ |
| Cementeries | 0,00 $Km^2$ | 280 $m^2$ |
| Thermal Plants | 0,00 $Km^2$ | 176 $m^2$ |
| Hibernacles | 0,00 $Km^2$ | 138 $m^2$ |
| Treatment Plants | 0,00 $Km^2$ | 94 $m^2$ |
| Service Areas | 0,00 $Km^2$ | 65 $m^2$ |
| Railways Green Areas | 0,00 $Km^2$ | 55 $m^2$ |
| Parking | 0,00 $Km^2$ | 46 $m^2$ |

*Table 32. Land Loss by Type (2100, RCP 8,5).*

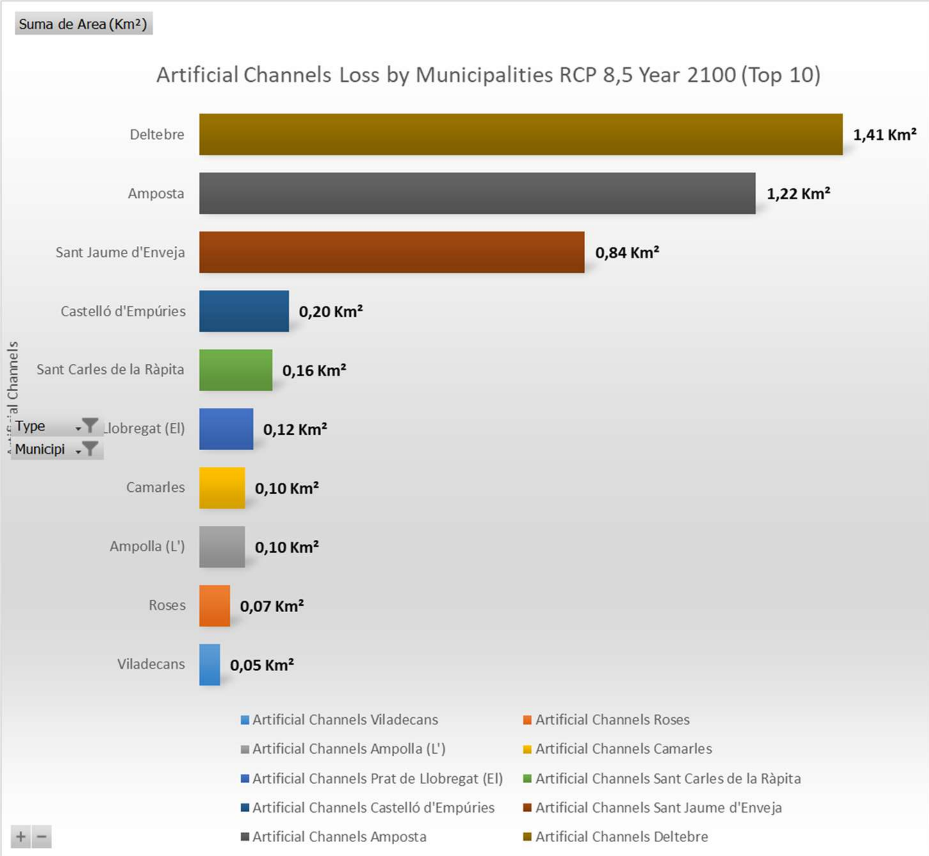



*Graphic 35. Beach Loss by Municipalities (2100, RCP 8,5).*

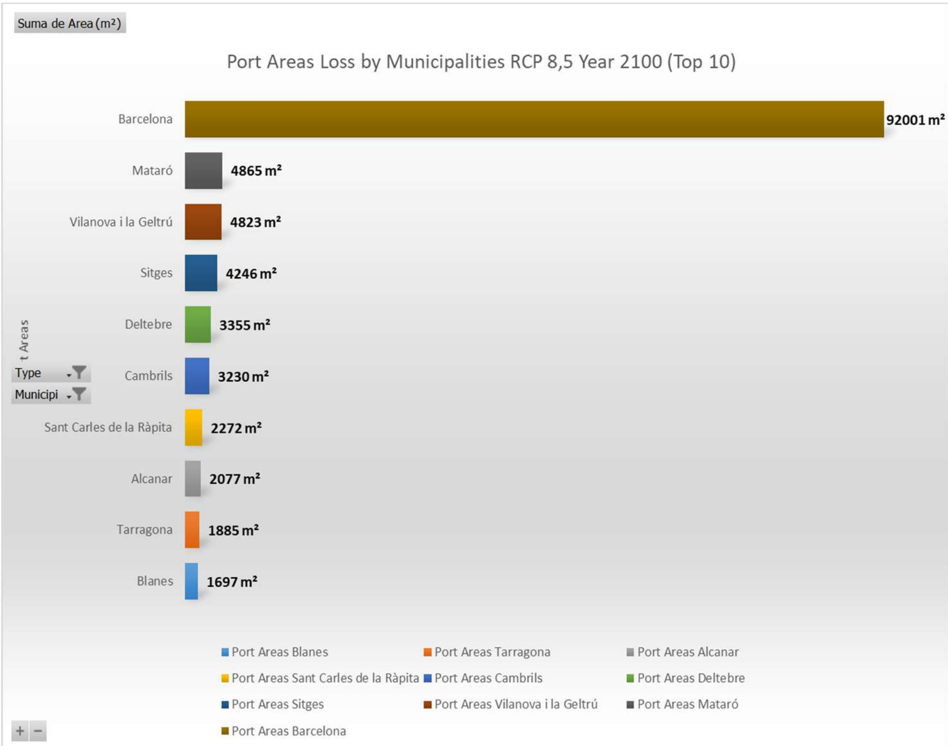

*Graphic 36. Airport Loss by Municipality (2100, RCP 8,5).*



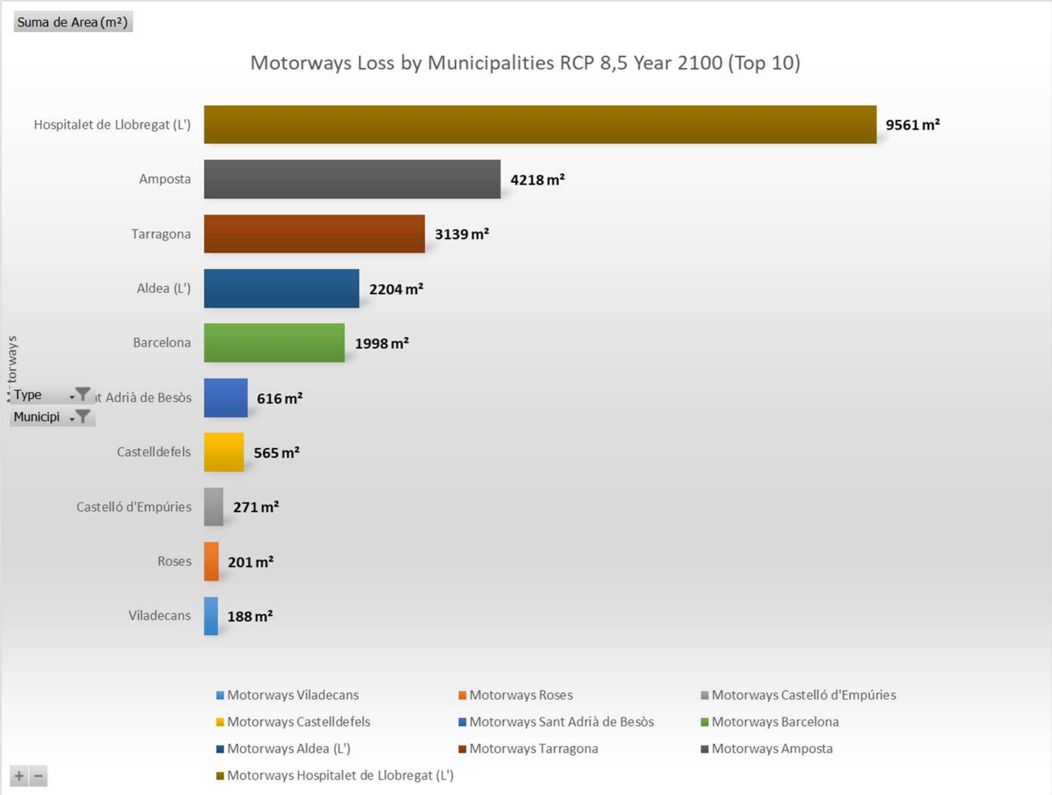

*Graphic 37.Agricultural Use Loss by Municipality (2100, RCP 8,5)*



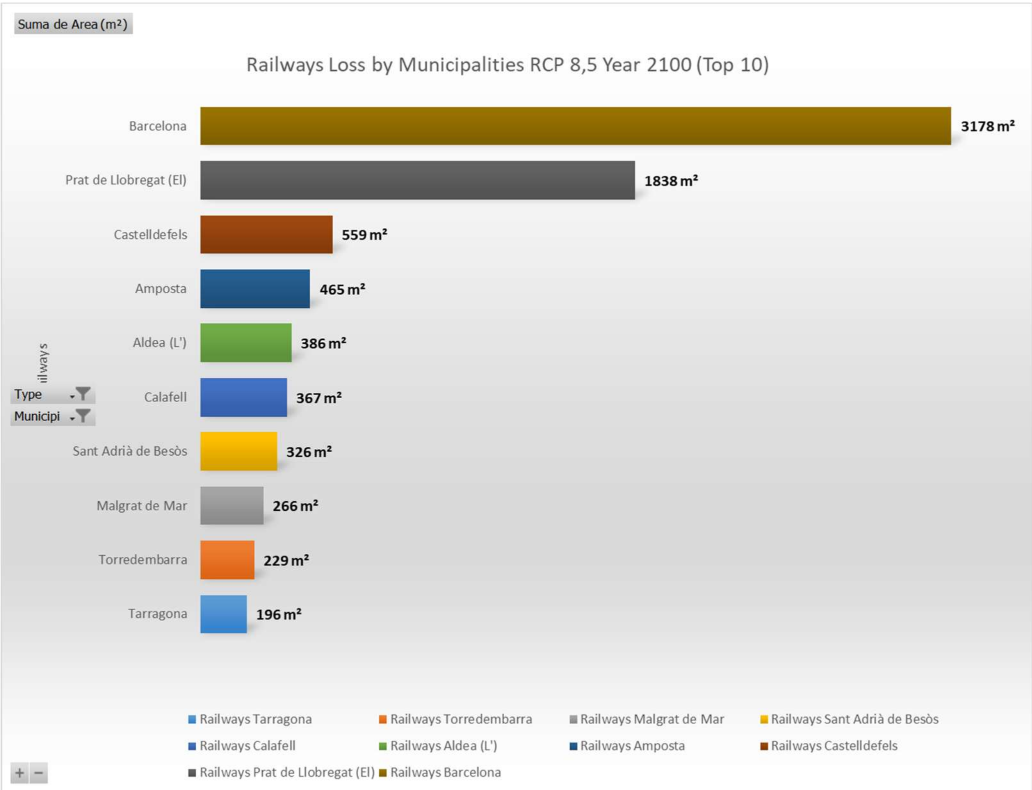

*Graphic 38. Artificial Channels Loss by Municipalities (2100, RCP 8,5).*



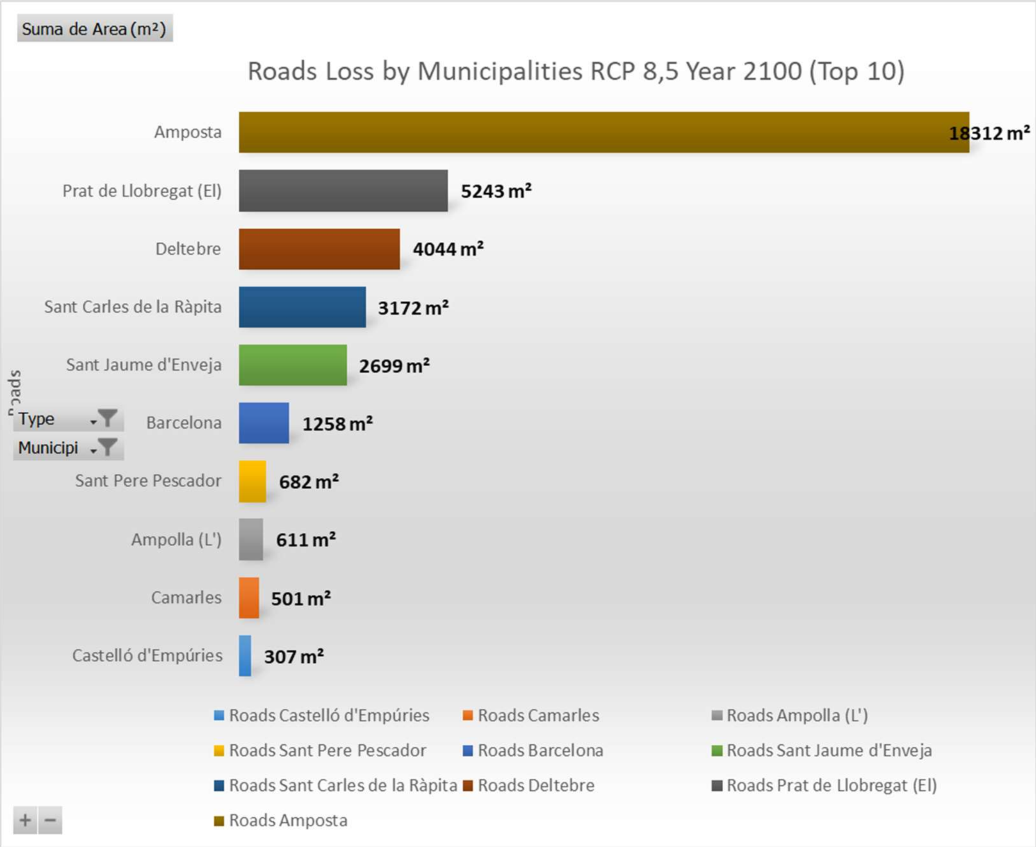

*Graphic 39. Port Areas Loss by Municipalities (2100, RCP 8,5).*



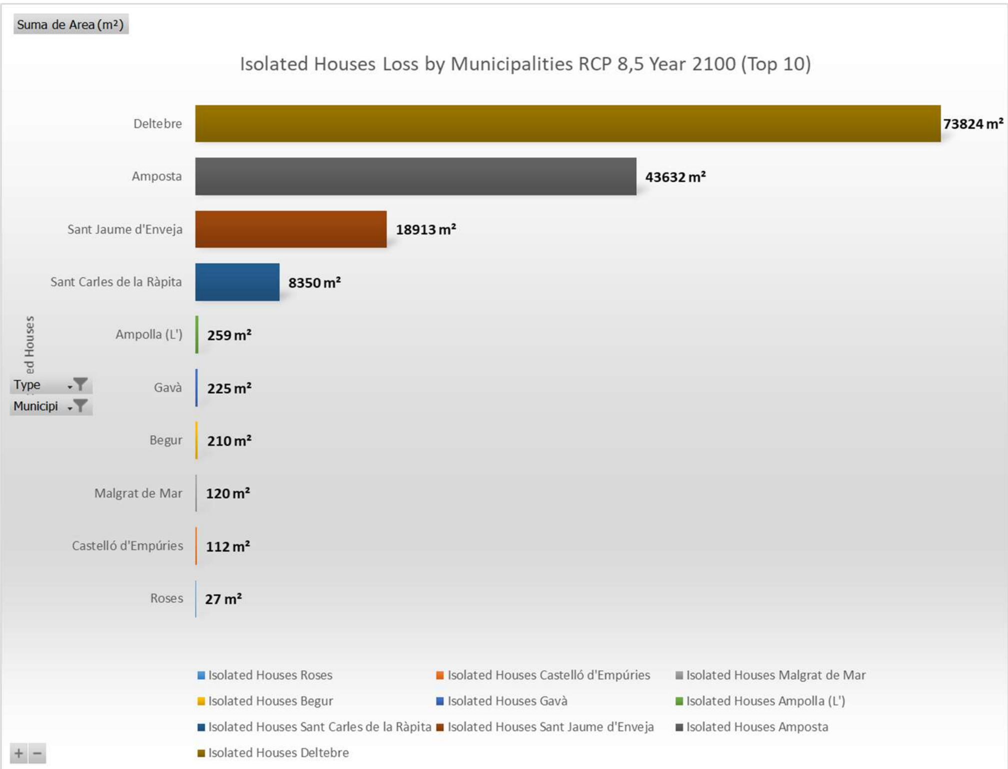

*Graphic 40. Motorways Loss by Municipalities (2100, RCP 8,5).*




*Graphic 41. Railways Loss by Municipalities (2100, RCP 8,5).*




*Graphic 42. Roads Loss by Municipalites (2100, RCP 8,5).*




*Graphic 43. Isolated Houses Loss (2100, RCP 8,5).*

# 4. Conclusions

After the results have been posted, we can gather some basic conclusions about this final thesis subject.

## 4.1 Geographical Conclusions

To start, there are 4 major zones where the breach inland from the sea is made clear by all our estimations, those areas being the **Roses Gulf**, **L'Estartit**, **El Prat** and the most vulnerable of them all, **Ebre Delta**. A great economic investment will be needed in order to preserve the environment and guarantee the correct functioning of each and every one of the economic activities that take place in these zones, with their respective land uses.

**Roses Gulf** and **L'Estartit** hold ecosystems of vital importance like the wetlands of **Aigüamolls del Empordà**, **Fluvià Delta** or **Ter Delta**. In addition, the beaches, campings, marinas and artificial channels of **Empuriabrava** and **Roses** are key elements for the correct development of their main economic activity, tourism and leisure.

**El Prat del Llobregat** is another threatened area, not only because the sea level rise has the potential to generally affect more than 30 different land uses, but also because one of these uses is an infrastructure of vital importance for Catalonia, **El Prat airport**. Our estimations tell us that around 40.000 m² of airport land use could be under sea water in the future, including areas very close from landing tracks, and flooded landing tracks are never good news.

**Ebre Delta** is the last of those vulnerable areas but not the least, on the contrary, it is, without doubt, the one that suffers the biggest blow.

The **Ebre Delta** is the most humid area of **Catalonia**, with an area of 320 Km². It is one of the most important aquatic habitats in the western **Mediterranean**. The sensitive balance between the natural heritage and the exploitation by humans has not been easy along the history, so the **Government of Catalunya** approved the creation of the **Natural Park of Delta de l'Ebre**, that occupies the regions of **El Montsià** (south of the river) and of **El Baix Ebre** (north of the river). The river **Ebre** is the responsible for the replenishment of the sediments and it has created the 3rd biggest delta in the Mediterranean only behind Nile and Rhône river deltas. Environmentally talking it has naturally created a safe port for more than 90 species of birds, which nidify in the river bed during winter, and serves as a step zone for many other migratory birds. It is also key for 8 different types of plants. The **Delta** is synonym of home for more than 50.000 people. Inside its geographical borders includes 2 regions (**El Montsià** and **El Baix Ebre**), 4 municipalities (**Deltebre, Sant Jaume d'Enveja, Amposta** and **Sant Carles de la Ràpita**), many urbanizations like **El Cava, Riumar, Els Muntells** and **L'Eucaliptus** and more than 30 different land uses, among them, agricultural and aquaculture use, fishing and tourism, for an estimated total annual economic value of around **100M €.** [38]

Our calculations tell us that Ebre Delta will lose between a **third and half of its total land mass during the 21st century**, which puts the area in priority number one for future "anti-SLR" measures.

Apart from those 4 mentioned areas, the entirety of the coast will suffer generic and local problematics related to SLR, beach extension loss being the most common of them. It is worrying to think that once the buffer zone that acts as a shield, which is the beach, disappears or thins down to minimal amplitudes, the next line of defense will be the infrastructures themselves. We are already starting to see this problem during winter storm events, when some parts of **El Maresme** train services (**RENFE**) must cut their service due to sea water invasion of the tracks from high waves or when maritime promenades must close to the public due to partial destruction of some of their parts. This kind of events, logically, will happen more usually with a higher sea level.

Focusing on land uses, beach, delta and agricultural use will be the main focus of SLR along this century. As said, they will act as shields for other areas, but once this century is over, the affected parts will be gone for good. If SLR gets worse during the next century, very serious considerations and investments will have to be taken in order to apply efficient measures of protection.

### 4.2 Model Conclusions

The **Bathtub** model is a great methodology to give us an approach for flooding events of any kind.

Bathtub models have been used to identify areas that may be subject to sea level rise. It gives a simplified yet very powerful visualization of the problem with a relative small amount of inversion of calculus and time. However, a bathtub model only considers the elevation of the ground above a reference elevation for determining SLR vulnerability. In a bathtub model the terrain is considered to remain constant. As the sea level rises, inundation occurs at locations between above the zero datum and below the new sea level, thus we can get some misleading information using this criterion.

The main disadvantages of this type of model is that is does not consider the coastline or urban water control infrastructures such as dikes and canals that lead to **overestimation** of flooding, or groundwater levels and storm surges that can lead to **underestimation** of it.

An example of this is the railways of Barcelona. According to our results, a relative amount of land use classified as railways in Barcelona will be affected by SLR, despite being hundreds of meters inland. The model identifies certain areas of

[38] (Wikipedia cooperators., 2017)

the railway system as under the new sea level, therefore those areas are classified as potentially floodable. We know that those areas are a very unlikely subject to flooding but nevertheless we must consider them if we are studying low lying areas. This kind of mistakes can be corrected with a better knowledge of the territory and consequential model depuration.

Yet, in other zones, we can have the opposite effect, in low lying coasts, where groundwater may impact soil storage capacity and create inundation in areas not otherwise contemplated under current modeling methods.

Thinking that one effect cancels the opposite would also be a mistake, because such considerations implies that the amount of land under the new sea level equals the amount of land that could have a potential flood due to overcapacity of soil storage, and that's a big uncertainty which we cannot account for.

Even after all these cons, the methodology proved to adapt very well to the behavior predicted by ICCP, and, such is it, that many important organizations like NOAA, use it regularly for their own research.

Another important part of the mistakes and work comes from raster data and its processes. The land is constantly changing, in this study we used data that was captured between 2008 and 2011. Despite being only 9 to 6 years old, many things could have changed. We need smart data recollection systems to be implemented with more ease of access and sharing policies. A clear example of this problem can be found in Delta del Ebre, according to our land uses layer, many of the land in the delta is classified as "others" (or coastline as I named it), but we can clearly see from platforms like google maps or our own orthographic picture, that it wasn't the case, since almost the totality of the Delta is used for agricultural and aquaculture purposes. This misleading information leads us to the wrong conclusion that agricultural use is not inside the top 5 of land uses affected by SLR, when, in reality, it is.

Finally, having to download hundreds of different grids of information from a website is not time efficient nor fair for users that want access to the data for different purposes. We are supposed to be entering in the era of the big data, where many types of data are collected and shared freely among the society. Many of the work carried out in this study was done for gathering data, downloading, and resampling it into manageable layers, which added to a low computer profile, was a huge handicap for this student. Luckily all these barriers were sorted out and we could arrange a decent study.

### 4.3 Personal Conclusions

In spite of this, one could say that the time invested in this study has been, at least, within the normality of that a final thesis deserves and must have, since much of the time has not been invested in the development of the model but, due to my own inexperience, was rather invested in learning the correct functioning of the software ArcMap and its functions, in order to present a model that can be considered serious in the research for climate change and its inherent problem, the sea level rise.

The good thing about ArcMap is that it offers many possibilities of calculation. There's always another way to get to the desired operations, when some of the ways prove inviable due to calculus weight or other errors.

After all, this software is used by a wide range of the scientific community and I learnt a lot of useful tricks and mechanisms that could be useful for myself in future studies or researches. I believe there are yet many challenges ahead for us and software of the kind of ArcMap, combined with bathtub-ish like methodologies, may prove invaluable in the years to come.

On the other side of the models themselves, I am afraid that they won't be enough in order to halt the advance of the seas.

Due to the scarcity of sediment for many sectors in the Catalan coast, the actions undertaken in the last 20 years (also extensive for the rest of the Spanish territory) have been unsuccessful to maintain a sandy belt as required by tourism and hinterland protection. New coastal strategies incorporating the whole river catchment basin and targeting medium to long term scales, moving from protection to a more proactive policy would increase the overall coastal sustainability. However, there has not yet been a general change of the policy and in many cases coastal management continues along the old track. Because of that, municipalities are starting to play a more active role demanding not only economic resources but also making proposals for maintaining a minimum beach width to ensure beach functions. This translates into a reactive management which will not solve the problem at long term. We need brave governments assessed by concerned individuals in order to undertake the necessary actions to prepare at least the most vulnerable zones of our coasts for what's to come.

As mentioned in the study, the sea level rise is a global problem and is not going to be solved in a short period of time. Multidisciplinary teams of engineers and scientists must be assembled together to engage this problem on the long term, not in the short one. Filling beaches with sand is not a solution, it just postpones it. And while we are discussing if the necessary measures should or should not be applied, whatever those are, time runs fast. Earth is making us clear that it won't stop for us nor anybody, we must adapt or face the consequences, and that, for me, is the single most valuable thing you can learn from climate change. As humans, I believe we are the most gifted species of the planet, possessing the best intelligence and knowledge, it would be irresponsible from us not to put those qualities at work to ensure not only the future of our own kind and cities, but from the future of the diversity of all the other species that coexists with us.

Last but not least, researching for the topic of this thesis made me contact the real world, in a way, that sadly, very few times I have achieved in the studying of my career. For once I could say that what I was doing had some sense into understanding real problematics from the world outside of the university. Maybe it is just part of the process of growing old, learning the boring basics in order to be able to understand the advanced, or maybe it is because the current educational system does not do enough to engage student’s curiosity for finding their vocation rather than teaching them standardized methodologies that lobotomizes their minds into boring chain processes of action-reaction, or, as the famous song says, converting them into another brick in the wall.

Be it one or the other, I am happy to say to myself than doing this research was not only a personal quest for finding my vocation but a necessary exercise for myself. Feeling that you are connected with something that’s real, to contribute into something important, not only makes you feel more alive but, It is an emotional exercise that everyone should be given the opportunity experience. And this, is the best I take with me from all.

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